OPTIMIZING MOISTURE AND NUTRIENT VARIABILITY UNDER DIFFERENT CROPPING PATTERNS IN TERRACED FARMS FOR IMPROVED CROP PERFORMANCE IN NAROK COUNTY, KENYA

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A Thesis Submitted in Partial Fulfilment for the Award of Doctor of Philosophy in Dryland Resources Management

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Declaration

I Alice Chepkemoi Ruto do declare that this thesis and its content is my original work and that to the best of my knowledge, it contains no materials previously accepted for any academic award of any other institution of higher learning. Where the works by other scholars have been used due acknowledgement has been made in the text. With approval of my supervisors, I submit this thesis to the Board of Postgraduate Studies for the award of degree of Doctor of Philosophy in Dryland Resources Management.

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Dedication

I dedicate this work to the almighty God for bringing me this far

To my family for their comprehensive support and prayers

All my friends, classmates and colleagues

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Abbreviations and Acronyms

AEZ	Agro-Ecological Zone
ASALs	Arid and Semi Arid Lands
CAADP	Comprehensive African Agriculture Development Programme
CIMMYT	International Maize and Wheat Improvement Centre
CCAFS	Climate Change, Agriculture and Food Security
CP	Cropping pattern
EMG	Environmental Management Group
FAO	Food and Agriculture Organization
ICARDA	International Centre for Agricultural Research in the Dry Areas
IFAD	International Fund for Agricultural Development
ITCZ	Inter Tropical Convergence Zone
LAI	Leaf Area Index
LPG	Length of Growing Period
MASL	Meters above sea level
NEMA	National Environment Management Authority
RCBD	Randomized Complete Block Design
SSA	Sub-Saharan Africa
SOP	Standard Operating Procedures
TC	Total Carbon
TN	Total Nitrogen
UNCCD	United Nation Convention to Combat Desertification
USDA	United States Department of Agriculture

Abstract

Terraces have been used to regulate, discharge excess runoff and reduce soil loss, however its ability to harvest and store water in the terraced field has not been fully investigated. A field experiment was therefore carried out in Suswa, Narok County during the short and long rain seasons of 2013-2015 to assess the variabilityof soil moisture and nutrients in terraced field and the effect it has on crop performance under different cropping patterns with a view of developing an appropriate cropping pattern that will maximally utilize the harvested water and the accumulated nutrients for promotion for adoption by farmers in drylands where low soil moisture and nutrients are a challenge. A randomized complete block design was used with maize and beans as the test crops. The treatments were; CP1: Maize and Bean intercrop in the upper and lower terrace position and sole maize in the middle, CP2: Maize and Bean intercrop in the upper and lower terrace position and sole bean crop in the middle, CP3: Sole maize crop in all the three terrace slope position, CP4: (control) where terrace was not maintained and CP5: had intercrop of maize and beans in all slope positions. Observations were made on soil moisture, pH, N, P, K and C, uptake of N, P, K by maize and plant growth including height, number of leaves, leaf area index (LAI), grain and biomass yields at different slope position during the four seasons. Gross margin analysis was done to evaluate the profitability of maize and beans production per cropping pattern and slope position. The results indicated that the lower terrace position had the highest moisture content at 30, 50 and 75 cm depths in all seasons, however CP3 had the highest soil moisture (19.91%) while CP4 had the least (14.1%) at 50 cm depth in season I (August to December, 2013). N, P and C were significantly ($p<0.05$) affected by slope position with the highest values recorded at the lower slope position, resulting in improved nutrient uptake in both maize above ground biomass and grain. The middle slope position had the least P uptake (1125 ppm) compared to the lower position (1703 ppm) in season IV (January to May, 2015). The lower slope positions had the highest K uptake while the upper positions had the least in all seasons. On average grain uptake of N in the four seasons was 1.53% in the lower and 1.26% in the upper slope positions. The same trend was observed in nutrient uptake by maize grain. There were significant differences ($p \leq 0.05$) in growth parameters; height, LAI and number of leaves as affected by slope position and treatments in all seasons. These parameters were found to be highest in the lower slope position compared to the upper position. Similarly CP4 recorded the least crop performance. There were significant differences ($p \leq 0.05$) in maize and bean grain yields at different slope positions and treatments in all seasons. CP1, CP2 and CP5 had on average the highest (above1000 kgha^{-1}) bean grain yields whereas CP4 had the lowest (670 kgha^{-1}). CP1, CP2, CP3 and CP5 recorded the highest (6.8) maize grain yields whereas CP4 had the lowest (3.5 tha^{-1}) in season I (August to December, 2013) and III (August to December, 2014). The lower slope position had the highest (6.23 tha^{-1}) maize grain yields compared to the upper slope position (below2 tha^{-1}) in all seasons. Likewise the highest gross margins (196,331; 100,265) were realized in the lower slope position with the upper position recording the least (51,881; 4,745) for maize and beans respectively. CP4 (control) had the least gross margins for both crops. There was no significant difference in yields and gross margins of sole maize crop and intercrops in all seasons. CP 3 (sole maize) had comparable (120,551) gross margins with intercrops, CP1 (117,986) and CP2 (118,526), meaning that the farmer can get more value for land, time and labour by intercropping. The study found that CP2 (Maize and Bean intercrop in the upper and lower terrace position and sole bean crop in the middle) was the most favourable for the study area. The investigation concluded that terracing had effect on productivity and farmers can benefit from the spatial nutrient and moisture variability as a low technology precision farming for increased yields.

CHAPTER ONE

1.0 INTRODUCTION

1.1The drylands

The Food and Agriculture Organization has defined drylands as those areas with a length of growing period (LGP) of 1–179 days (FAO, 2000a), which includes regions classified climatically as arid, semi-arid and dry sub humid (other than polar and sub-polar regions). The United Nations Convention to Combat Desertification (UNCCD, 2000) on the other hand uses the ratio of mean annual precipitation to mean annual potential evapotranspiration (P/PET) to classify drylands. This value indicates the maximum quantity of water capable of being lost as water vapour in a given climate by a continuous stretch of vegetation covering the whole ground and well supplied with water. Under the UNCCD classification, drylands are characterized by a P/PET of between 0.05 and 0.65.

Drylands cover 41 percent of the earth's terrestrial surface, and although they occur in every continent, they are most extensive in Africa. They are home to a third of all humanity (over 2 billion people). About 16% of this population lives in chronic poverty, however dryland agro-ecosystems include a diverse mix of food, fodder and fibre crops; vegetables, rangeland and pasture species; fruit and fuel-wood trees; medicinal plants; livestock and fish. Getting this mix right can contribute to alleviation of poverty, enhanced food security and ensure environmental sustainability in dryland agro-ecosystems (Parry *et al*., 2009).

Predictions indicate that with climate change two-thirds of Africa's arable land and the livelihoods of small holder farmers could be lost 2025 (UNEG, 2011). It is also expected that climate change will cause grassland productivity to decline by 40–90% in semi-arid and arid region where as high levels of desertification and soil salinisation, and increasing water stress will occur in parts of Asia, Sub-Saharan Africa and Latin America (IPCC, 2007). All this is anticipated to result in a fall in production between 9-11% by 2070 (Parry *et al*., 2009). Agricultural production systems in dry areas are over-stretched, about two-thirds of global dryland area is used for livestock production. Dryland systems are characterized by persistent water scarcity, rapid population growth, frequent droughts, high climatic variability, fragile soils, land degradation and desertification, and widespread poverty (Solh and van Ginkel, 2014). Low nutrients and soil moisture deficit are key challenges to sustainable production in the drylands. To ensure the future livelihoods of dryland farming communities, it is critical to manage risk more effectively and enhance productivity through diversification and sustainable intensification of production. Special attention should be focused on how to minimize the adverse effects of increasing land for increased production and water salinities. In the case of water scarcity, there is need to focus on production per unit water other than per unit area (Solh and van Ginkel, 2014). Dryland degradation, costs developing countries an estimated 4–8% of their national gross domestic product (GDP) each year. During drought periods, dryland populations migrate to other areas in search of pastures for their livestock and income, either in cities within their own country, camps where relief services are provided or in less stricken areas in other countries. This therefore calls for concerted efforts to manage the drylands (UNEG, 2011).

Kenya is divided into seven agro climatic zones using a moisture index (Sombroek *et al*, 1982) of annual rainfall expressed as a percentage of potential evaporation (Eo). Areas with an index of greater than 50% have a high potential for cropping, and are designated zones I, II and III. These zones account for 12% of Kenya's land area. The semi-humid to arid regions (zones IV, V, VI and VII) have indexes of less than 50% and mean annual rainfall of less than 1100 mm (Bekure *et al*., 1991). These drylands (Arid and Semi Arid lands or ASAL) make up over 84% of the total land surface and support about 9.9 million Kenyans, approximately 34 % of the country’s population (Barrow and Mogaka, 2007), also reported that there are about 9 million ha (19%) which can support rain-fed agriculture, 15 million ha (31%) devoted for more sedentary forms of livestock production and the remaining 24 million ha (50%) is drier and suitable only for pastoralism. According to the First National Communication of Kenya to the Conference of the Parties to the United Nations Frame Work Convention on Climate Change (GOK, 2002), Kenya's geographic location makes it inherently prone to climate driven cyclical droughts and floods which are set to increase in both intensity and frequency due to global climate change. Pradeep (2009) reported that serious repercussions are expected not only on agricultural productivity but also in the achievement of poverty reduction and other Millennium Development Goals. This is because livelihoods and economic activities in Kenya are highly vulnerable to climatic fluctuations, with the Arid and Semi-arid Lands (ASALs) being among the most vulnerable to droughts and to long-term climate change. Barron (2009) reported that variable rainfall results in poor crop water availability; hence reducing rain fed yields by 25- 50% of potential yields, often less than 1 ton cereal per hectare in South Asia and Sub-Sahara Africa. This low agricultural productivity often offsets a negative spiral in landscape productivity, with degradation of ecosystem services through soil erosion, reduced vegetation cover and species decline.

Suswa area of Narok is transitioning from pastoralism to agropatroralism and previous communal land has been sub-divided and fenced hence livestock movements are restricted. Suswa hills are eroded with some of the gullies reaching depths of over 25 m and widths of over 30 m (Odini *et al*., 2015). The area has sharp gradient and volcanic-ash soils that are vulnerable to erosion and in addition, the land continues to be depleted of ground cover making it vulnerable to erosion. Torrential rains often pound on the vulnerable bare grounds, leading to formation of gullies (Maina, 2013). As part of the rehabilitation and management of the Suswa gullies there was need to look into other ways of addressing land degradation at the same time give the community alternative livelihood by introducing soil and water conservation measures, dry-land farming and bee keeping.

1.2 Crop production constraints in drylands

The major crop productions of problems of arid and semi-arid areas are insufficient soil moisture for plant growth and low amounts and imbalances of available plant nutrients. In these dryland regions moisture stress is not only a function of low and unpredictable rainfall but also of the ability of the soils to hold and release moisture. Important features of dryland soils for agricultural production are low water holding capacity and inability to supply nutrients for plant growth. There is little deposition and accumulation or decomposition of organic materials in dryland environments hence the organic content of the soils is often low and therefore, natural soil fertility is also low (Koohafkan and Stewart, 2008). Such soil has negative impact on crop yields which will worsen as farmers face climate change with its associated increased incidence of drought, intense rainfall, and disruptions in rainfall patterns. In these semi-arid areas inadequate soil moisture for plant growth aggravates the problem of soil fertility. The quantity and distribution of rainfall, results in crop yield losses and in some cases total crop failure. These losses can greatly aggravate food insecurity, especially in regions with high population (Winterbottom *et al.*, 2013).

Rainwater harvesting and management has a high potential for improving food security and reducing over-dependency on food aid. Traditional water harvesting systems are characterized by flexibility and endurance and have been used overtime by the people who live in marginal environments. Different regions have different low cost techniques that have ensured increase in water use efficiency and conservation (Ngigi, 2006). Soil moisture conservation measures such as conservation tillage, runoff catchment systems, residue mulching, application of organic manure and conservation terraces are among the recommended practices for increased crop production in ASALs (Biamah *et al*., 2004). However, lack of adoption of modern farming technologies and the farmers’ inability to replenish nutrients lost in continuous cultivation and erosion has exacerbated problems of soil moisture in drylands to an alarming extent. There is an increased risk of crop failure and poor yields caused by mainly rainfall variability and the farmers need skills to successfully grow their crops in dry areas. This study sought to improve both soil and water productivity by developing appropriate cropping pattern that will take advantage of soil moisture and nutrient variability in terraced fields in order to enhance crop production.

1.3 Problem statement

Terracing the world over has been promoted for use to control soil erosion, and to regulate and discharge excess runoff. Though terraces can contribute to increasing soil moisture content when maintained, their potential to harvest rainwater and improve moisture infiltration and storage along the terraced area has not been fully investigated. The farmers therefore, have continued to grow their crops in terracced fields without taking into account the variabilty in nutrient and moisture accumulation at the diffrent slope position and the most appropriate cropping pattern that will give them maximum benefits of the water harvested in the terrace ditch. In addition, arid and semi-arid regions, suffer from insufficient and unreliable rainfall and high rates of evaporation, to aggravate the situation (Pimentel and Burgess, 2013). This, calls for the efficient use of the limited amount of rainfall available and the development of field specific and field adapted mangement practices for each slope position for sustainable land use (Aung *et al*., 2013). This study was conducted to assess the variabilityof soil moisture and nutrients in the terraced field as affected by terrace and the effect this has on crop performance with a view of developing an appropriate cropping pattern that will maximally utilize the harvested water and the nutrient accumulation for promotion of its adoption by farmers.

1.4 Justification

Water scarcity remains the most limiting factor for agricultural production in the arid and semi arid regions and low annual rainfall is the main reason for food insecurity. The region is characterized by erratic and highly inconsistent rainfall, periodic droughts and dry spells, and low annual rainfall usually of no agricultural significance. Statistically severe crop reduction caused by dry spells occur in 1-2 out of 5 years and total crop failure caused by annual drought every 10 years. This situation is aggravated by high potential evaporation levels that range from 5 to 8 mm/day (Gash *et al.*, 1991) giving a cumulative evapotranspiration of 600–900 mm over the plant growing period and resulting in continual water scarcity and hence low yields. Ngigi (2003) attributes the water scarcity to poor rainfall partitioning resulting in large amount of non-productive water flows. Rockström (2000) argued that the actual cause of crop failure is poor distribution of rainfall other than absolute water scarcity and that farming systems regularly suffer from agricultural droughts and dry spells caused by management induced water scarcity. On-farm water balance analysis indicated that in savannah farming systems in sub-Saharan Africa less than 30% of rainfall is used as productive transpiration by crops and that on severely degraded land, this proportion can be as low as 5% (Rockström, 2003). This is usaully because under rain fed agriculture most water is lost through runoff and evapotranspiration. Consequently, crop failures commonly blamed on drought might be prevented in many cases through better farm-level water management.

In dryland rainfed farming the constraint is not only the erratic rainfall distribution but the amount of rainfall that can be stored in the root zone and its effective utilization. Increasing water availability for crops could be done by irrigation, but due to lack of available water resources this is often not an option in most dry lands. A more feasible option is to harvest and utilize the limited amount of rainfall received to cover the crop water demand. Water harvesting and soil moisture retention are simple options for increasing soil moisture, and have successfully been used in dry land farming situation around the world. Several studies have reported that by increasing soil water content, supply and retention, crop yields and hence food production and household income can be improved considerably (Binyam and Asmamaw, 2015; Botha *et al.*, 2007; Biamah *et al.*, 2004) through increase in biomass production per unit land and per unit water. In view of this, it is thus important that appropriate farm practices for soil moisture conservation are developed and promoted for adoption by farmers, as poor yields in combination with a large population growth has often led to food shortages (Woltersdorf, 2010).

While erosion control measures like cut off drains and terraces percieved only as soil conservation measures for use to regulate and discharge excess runoff, they also act as water harvesting structures as they help concentrate water around the root area (Thomas, 1997). Rain water management through construction of terrace ditch can therefore serve both as a soil and water conservation measure. In a field experiment in Machakos County, Gachene *et al.*, (2011) established that the crop next to the ditch was perfoming better due to the luxurious consumption of water, while the crop in the middle position was suffering from moisture stress (Plate 1).

Lower terrace

Upper Terrace

Plate 1.1: Note the shorter plant height as you move away from the terrace (Gachene, 2011)

Aung *et al.*, (2013) in a field experiment to assess the spatial variability in soil properties and crop yield in Vietnam**,** reported that there was high silt and clay content in the middle and lower slope position while sand was dominant in the upper fields. Total nitrogen (TN) and total carbon (TC) contents were considerably higher in lower lying fields than the upper fields and grain yields were lowest on upper slopes increasing progressively down slope in both fertilized and unfertilized fields. This increase in yields was attributed to higher nutrient levels at the lower slope position. Despite these studies there is limited knowledge and understanding about sediment inducing spatial variation in soil properties (soil moisture and nutrients) and crop yield within the different slope positions due to upland soil erosion in terraced fields in the drylands of Kenya. This creates a need to undertake detailed studies on the variability of moisture and or nutrient in terraced farms and how they affect crop growth at different slope positions in order to maximize the use of the available water and nutrients in ASAL crop production. This study sought to establish the moisture and nutrient variability in a terraced farm and the effect it has on crop growth, with the goal of developing the most appropriate cropping pattern that will maximally utilize the harvested water in the terrace area and promote its adoption by farmers in Suswa area of Narok County.

1.5 Main objective of the study

The main objective of the study was to determine the most appropriate cropping pattern that will maximally utilize soil water and nutrients in the terraced farm for increased smallholder food production in moisture deficit areas of Narok County.

Specific objectives

i. To investigate the effect of terracing on soil moisture variability and selected soil chemical properties in a maize and bean cropping patterns.

ii. To assess the effect of terracing on nutrient uptake in maize above ground biomass and grain under maize and beans cropping patterns.

iii. To investigate the effect of terracing on crop grain yields and above ground biomass under maize and beans cropping patterns

iv. Determine the profitability of maize and bean production under different cropping patterns in a terraced field.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Drylands all over the world not only suffer from low annual and but erratic precipitation that is subject to temporal and spatial variability. This rainfall variability generally increases with a decrease in annual amounts and it is particularly high in the Sahelian Countries which are known for their periodic droughts that sometimes last several years. Further variations occur considerably within the same drylands from one location to another. Dore (2005) argue that while rainfall in many drylands average between 2000-500 mm/year, which may support crop growth, the fluctuation from year to year make such averages of little use because it is difficult to use such averages for planning agricultural development (Dore , 2005).

Water scarcity is a common phenomenon resulting from insufficient rainfall especially in the arid regions. While the semi-arid regions may receive enough annual rainfall to support crops, the rainfall is distributed so unevenly in space and time that rainfed agriculture is barely possible. The rains in semi-arid regions also tend to fall in a few intense showers leading to large amounts of runoff going into drains and eventually seeping down to the groundwater or to rivers. The drylands are further characterized by large ratios of evaporation to precipitation, exceeding 95% in some areas. This results in low moisture most of the year which in turn negatively influences nutrient availability and uptake, therefore influencing vegetative growth (Hassan, 2003). Due to these conditions water deficit remains the biggest limiting factor and the greatest challenge for sustainable agricultural production and development in the drylands. Despite this over 30% of the world's populations live in these regions. Since rainfall is difficult to capture for agricultural use, it means that there is need to device ways and means and methods of keeping the water in the soil so that it is available for plant growth in the drylands (Pimentel *et al*., 2004).

2.2 Water resources for agriculture in the drylands

Water availability is the key limiting factor for food production across all dryland areas. Countries within the drylands suffer from severe groundwater depletion and salinity, compounded by rapid natural resource degradation and desertification. The Middle East and North Africa are the most water scarce regions in the world, and the problem is set to deteriorate. The drylands have less than eight per cent of the world's renewable water resources and are challenged by extreme temperatures, frequent drought, land degradation and desertification. The occurrence of droughts compound water scarcity and results in famine whose impact is felt more in the poorest countries. Such famines and disasters have hit drylands with increasing intensity and have, together with the escalating food prices, led to political unrest in many countries. In contrast, many drylands can experience periodic excessive rainfall that can cause flash floods and consequently, loss of life and property (Brooks *et al.*, 1997). With climate change, such events may become even more frequent (ICARDA/CCAFS, 2012).

Although water is considered a renewable resource, its availability is limited in terms of the amount available per unit time in any one region. The average precipitation for most continents is about 700 mm/yr but varies among and within them (Shiklomanov and Rodda, 2003). A nation is considered water scarce when the availability of water drops below 1,000m^3/capita/yr (Jimenez and Asano, 2008). The major factors influencing water availability include rainfall, temperature, evaporation rates, soil quality, vegetation type, as well as water runoff. Thus Africa, despite having an average of 640 mm/yr of rainfall, is relatively arid since its high temperatures and winds foster rapid evaporation (Pimentel *et al.,* 2004). Surface runoff events, soil-moisture storage, and groundwater recharge in dryland regions are generally more variable and less reliable than in wetter regions. Further more available water in most drylands is affected also by salinity and mineralization

(Koohafkan and Stewart, 2008). This therefore means that for sustainable farming in the drylands there is need to focus on rainwater harvesting for supplemental irrigation.

2.3 Dryland farming

Dryland farming is the cultivation of crops without irrigation in regions of limited moisture. It is mainly practiced in regions inherently marginal for non-irrigated agriculture and hence risks of crop failure and poor yields in a dry year are high. Nanwal *et al.,* (2012) grouped dryland farming into two categories depending on the amount of rainfall received. The first category is where cultivation of crops is done in areas where annual rainfall is less than 750 mm as practiced in arid regions with the help of moisture conservation practices. In these regions crop failures due to prolonged dry spells during crop period are most common. The second category is when cultivation of crops is done in areas where annual rainfall is more than 750 mm but less than 1150 mm. In this category dry spells may occur, but crop failures are less frequent. In dryland crop production, the major challenge is to conserve precipitation water appropriately for use during crop growth. Usually higher evapotranspiration (ET) than the total precipitation is the main reason for moisture deficit. The conservation of precipitation water for crop production is very vital and it is therefore imperative that farming practices conserve and utilize the available rainfall efficiently. This implies that soil and moisture conservation measures are therefore key for dryland farming practice in semi-arid regions and drainage facility may be required especially in black soils. To optimize water storage under any precipitation condition, the soil should have enough infiltrability, permeability and capacity to store water (Pal *et al.*, 2009).

Large proportions of the population in Sub-Saharan Africa derive their livelihoods from rain fed agriculture and thereby depend directly on rainfall and agricultural productivity for their survival. Drought is Africa’s main form of natural disaster which often affects rain fed agriculture severely. For cereal crops rainfall amounts are on average too low for optimal crop yields, prolonged dry spells lead to food, forage and water shortages resulting in significant decrease in agriculture production Crop performance and yield are influenced by amount of rainfall and distribution throughout the growing period. Consequently, constant evaluation of potential yield of the crop throughout the growing period need to be done so as to decrease inputs such as fertilizer and weed control in the likelihood of poor yields or crop failure due to insufficient moisture. Conversely, in years when moisture is abundant, farmers may increase their input efforts and budget to maximize yields and to offset poor harvests (Pauw, 2011). Water from rivers, lakes and wells in most arid regions may have problems of quality, due to the presence of excess minerals. Salinity affects plant growth and water quality, resulting in lower crop yields and reduced agricultural production. Increased salinity in most plants may not only result in difficult extraction of water from the soil but also an imbalance of plant nutrients in the soil (Creswell and Martin, 2002). The use of this water for irrigation may lead to the accumulation of salts in the soil resulting in alkalinity or salinity, which will limit crop production. The removal of salt from the soil is very difficult and expensive (Creswell and Martin 2002; Green, 2008). In Kenya, for example, about 40% (25 million hectares) of land have salinity and or sodicity problems (Attibu, 2014). ASAL covers approximately 80 – 83% of the country and receives less than 700 mm rainfall per year which is erratic, poorly distributed and cannot support rain fed agriculture. This leaves irrigation as the only option for expanding cropping fields, meaning that there is need to manage the available water appropriately by harvesting it, conserving it, using it efficiently and avoiding damage to the soil.

Late onset and early cessation of rains are other challenges faced in dryland farming resulting in delayed planting and hence poor yields. When the rains cease early in the season the crop is exposed to drought during flowering and maturity stages which reduces the crop yields considerably. Prolonged dry spells that occur during crop period reduces crop growth and yield and may also lead to complete crop failure when unduly prolonged (Creswell and Martin, 2002).

Droughts and dry spells affect both soil water and plant water uptake capacity. The transpiration capacity of a crop is affected by droughts and dry spells, but the size of the reduction in transpiration and the subsequent effect on crop yield will vary depending on the development stage of the crop (Rockstrom and Barron, 2010). In addition most drylands tend to be windy and hot. Heat and wind increase rate of evaporation and therefore increases the effects of aridity. Wind may also cause mechanical damage to crops (Creswell and Martin, 2002; Mwenzwa, 2011). Plants transpire to compensate for high temperatures resulting in great losses of moisture from the soil. The process of evapotranspiration moves water vapour from ground or water surfaces to an adjacent shallow layer that is only a few centimetres thick. When this layer becomes saturated evapotranspiration stops. However, wind can remove this layer replacing it with drier air which increases the potential for evapotranspiration. Winds also affect evapotranspiration by bringing heat energy into an area. A 5-mile-per-hour wind will increase still-air evapotranspiration by 20 percent; a 15-mile-per-hour wind will increase still-air evapotranspiration by 50 percent (Burba *et al*., 2013).Both heat and wind can be controlled by changing the microclimate. The effects of winds can be reduced by windbreaks (lines of trees perpendicular to the direction of prevailing winds). As a general rule, a windbreak is effective over an area 2.5 times the height of the tree. One must however remember that a windbreak may also rob crops of light, water and nutrients. Thus, the advantages of a windbreak must be weighed against the disadvantages in any particular environment, especially in drylands where moisture and nutrients are often low. Windbreaks can also be constructed of non-living materials, which are likely to be expensive (Hipsey, 2002).

The impact of population growth in rural areas is pushing communities into unsustainable farming practices such as burning and razing of tropical forests, cultivating in steep slopes that are vulnerable to erosion, moving into fragile marginal eco-system, over cropping and over grazing and subsequent depletion of fragile arable land and over-utilization of ground water resources. Water resources for agricultural purposes are therefore getting scarce by the day, and there are hardly any land reserves to be brought into production to widen the agricultural base. It is projected that by the year 2025, close to three billion people in 48 countries will be affected by critical water shortage for all or part of the year (Duveskog *et al.*, 2003). This study used the terrace ditches to harvest rain water for improved crop production in drylands for the ever growing population.

One of the most crucial problems in agricultural areas today is depleted soils resulting in decline in yields. Soils lose their fertility as a result of chemical and physical degradation and/or nutrient depletion. Soil nutrient depletion and fertility decline are caused by among other things soil erosion Ovuka (2000). Human activity, such as conversion of forests to agricultural land, increased cultivation of marginal lands, overgrazing, and low-input or fertility-mining methods of subsistence agriculture practiced on marginal lands with steep gradients accelerate soil erosion. The sorting action of erosion removes large proportions of the clay and humus from the soil, leaving behind the less productive coarse sand, gravel and in some cases even stones, impairing the quality of the remaining topsoil. The removal of this organic matter affects soil properties including texture, structure, nutrient availability and biological activity and makes soil more susceptible to further erosion as its aggregates becomes less stable thus, negatively affecting crop production (Wolka *et al*., 2011).

The problem of low soil fertility in drylands is compounded by inadequate soil moisture that limits the extensive use of chemical fertilizers. Because of the low rainfall and consequently reduced plant growth, organic material is produced slowly and broken down slowly as well. Low soil fertility leads to low productivity, which results in less carbon (C) input to the soil, and eventually less water capture (Peterson *et al*., 2005). Drylands soils also show great diversity in texture, structure, type of clay, organic matter content and depth. These variations induce significant differences in infiltration rate, erodibility, moisture holding capacity, drainage characteristics, aeration, susceptibility to and recovery from compaction and general response to soil management and manipulation (Randy and Martin, 1998). Most soils in the drylands have a low moisture retention capacity due to low organic matter, in addition water that falls in arid regions may be of little use for crop plants because the amount is too small to penetrate the soil sufficiently, or it may run through a porous soil too quickly, or it may run off too fast altogether therefore not available for plant growth (Kirkby *et al*., 2005). The low levels of soil moisture and nutrients are further worsened in the sloppy areas where topography directly affects soil-forming processes through erosion and deposition. Aung *et al.,* (2013) in a field experiment to assess the spatial variability in soil properties and crop yield in Vietnam**,** reported that there was high silt and clay content in the middle and lower slope position while sand was dominant in the upper fields. Total nitrogen (TN) and total carbon (TC) contents were considerably higher in lower lying fields than the upper fields and grain yields were lowest on upper slopes increasing progressively down slope in both fertilized and unfertilized fields. They attributed the increase in yields to higher nutrient levels at the lower slope position.

Soil loss by the actions of water and wind is generally higher in drylands than in the more humid regions. In Morocco for instance, the annual loss of soil nutrients in agricultural areas located Northwest of the Rif Mountains is equivalent to $ US20/ha/yr. This represents about 90% to 180% of what local farmers invest yearly on fertilizers (Brooks *et al.,* 1997). Alemahyu (2007) reported that in Ethiopia, the average annual rate of soil loss is estimated to be 12 tons/ hectare/ year, a figure that is set to be higher on steep slopes and in areas where the vegetation cover is low. The Ethiopian Highlands Reclamation Study (EHRS) estimated that if soil erosion continued unchecked, by the year 2010 it was expected that some 38,000 sq. km of the highlands of Ethiopia would be washed down to bare rock and a further 60,000 sq. km would have a soil depth of 10 cm or less (Alemahyu, 2007). In addition Gebreselassie (2002) reported that in the Anjeni watershed station established for the soil conservation research programme (SCRP), the annual soil loss from the test plots without conservation measures was reported to be 90 to 110 tons on a 12% to 18% slope gradient respectively. Amare *et al.*, (2013) reported that the long-term impacts of soil and water conservation at Anjeni watershed in Ethiopia, reduced soils erosion, improved soil qualities and increased crop yields. Soil nutrients transported from the upper parts of the terrace were trapped by the conservation structures at the lower sides of the terraces and maintained there; making significant difference between the lower and the upper parts.

The displacement of soil materials by water has negative consequences as the removal of the fertile top soil reduces the productivity capacity of the soil, while in extreme cases the rooting depth can become restricted for agricultural crops. In fragile soils with a poor structural stability like most of the dryland soils, runoff water may lead to rapid formation of gullies by eating away valuable soils and making terrain eventually unsuitable for farming. Global assessment of soil degradation (GLASOD) approach distinguishes two forms of water erosion; one is the loss of topsoil known as surface wash or sheet erosion, where loss of topsoil is often preceded by compaction and/or crusting resulting in a decrease in the infiltration capacity of the soil. The second is the terrain deformation and this is the kind of erosion that results in rills and gullies rendering the land unsuitable for agricultural production. Control of gullies is difficult and restoration is almost impossible, as healing takes a very long time (Oldeman, 2000). Pimentel (2006) and Ananda *et al.*, (2003) reported that soil erosion is the biggest environmental problem the world faces second only to population growth. Worldwide erosion on crop land averages about 30t/ha/yr and each year about 10 million ha of crop land is rendered unproductive and abandoned due to erosion. Pimentel (2006) also reported that soil erosion is highest in Asia, Africa and South America where soil loses range from 30-40t/ha and that it is severe in small farms located in marginal areas where soil quality is poor and the topography often steep. Overall soil is being lost 10-40 times faster than the rate of soil renewal endangering future human food security and environmental quality hence there is need for careful management. Soil is a natural resource which is not renewable at least over the human timescale and very expensive either to reclaim or to improve once eroded physically or chemically (Oldeman, 2000). Angima *et al*., (2003), in a study carried out in Kanjuki, central Kenya established that the total annual soil loss predictions varied and ranged from 134Mgha^{-1} per year for slopes with average slope length and steepness (LS) factors of 0–10 to 549Mgha^{-1} per year for slopes with average LS-factors of 20–30. Similarly Gachene (1995) reported a soil loss of 247 tons/ha/year on 60% slopes for non-conserved maize plots and 93.5 tons for intercropped maize and beans and argued that soil degradation may not be reversible since fertilizers cannot fully compensate yield losses caused by soil erosion, hence need for conservation structures to prevent these losses.

For this reason all farm management practices should result in greater stimulation of activities of soil organisms, nutrient additions to the soil, minimal nutrient exports from the soil and optimal nutrient recycling within the farming system. Other soil fertility-enhancing interventions include improved fallows, biomass transfer and crop residues. In soil and water management, technologies that improve soil fertility and productivity are as important as those that reduce erosion and loss of water. These include practices such as residue mulching, contour tillage and tied ridging, minimum tillage, sub-soiling, crop rotation, cover cropping, rotational grazing, contour ripping, terracing and direct application of organic matter, farmyard manure and inorganic fertilizers (Mati, 2006). Crop production in drylands is also constrained by accelerated soil erosion, induced soil moisture deficits, soil fertility depletion, soil crusting and compaction. In the upland areas, the main problems are soil erosion, low moisture and low soil fertility, whereas in the lower areas incidence of water logging may be experienced (Biamah, 2005). This study hope to counter the negative changes in crop yields by identifying zones of moisture and nutrient accumulation in terraced fields and developing appropriate cropping pattern for improved yields .

2.4 Rainwater harvesting for crop production

The rising demands for food and uncertainties associated with climate change call for a paradigm shift in water management with a stronger focus on rain fed agriculture with emphasis on securing water to bridge the dry spells and to increase agriculture and water productivity (Rockström *et al*., 2010). Rainwater harvesting is an age old strategy that is used to sustainably manage water resources in the dry lands, it is an intermediate technology, in areas where rainfall is low or poorly distributed and or may be too unreliable for cropping (Ngigi, 2003). Water harvesting describes methods of collecting, concentrating and storage of various forms of runoff from a variety of sources for later use. Rainwater harvesting is increasingly becoming relevant where problems of environmental degradation, drought and population pressure are most evident. Barrow and Mogaka (2007) indicated that over 84% of this land is located in arid or semi-arid areas, where rainfall is irregular and much water is lost through runoff. Economic considerations suggest that water harvesting is most attractive where the harvested water can be used directly by crops on an adjacent area; next where water can be diverted to nearby crops or trees and least where the harvested water must be stored and used later as irrigation (Koohfakan and Stewart, 2008).

In- situ rainwater harvesting are soil management strategies that enhance rainfall infiltration and reduce surface runoff, such as terracing, pitting or conservation tillage practices. The in situ systems have a relatively small rainwater harvesting catchment typically not greater than 5-10 m from point of water infiltration into the soil. These technologies often serve primarily to recharge soil water for crop and other vegetation growth in the landscape. In- situ rainwater harvesting techniques emphasizes on water management and conservation (Kibasa, 2013). Such methods aim at maximum structures which are mostly traditionally considered for soil moisture conservation. This approach improves infiltration and minimizes surface runoff to achieve better yields where soil moisture is a constraint. Mostly *in- situ* rainwater harvesting is implemented to counter soil erosion, to recharge soil water for crop and other vegetation grown in the landscape, or to recharge shallow groundwater aquifers (Sivanappan, 2006). In-situ rainwater harvesting for crop production purposes is better achieved through integration of conservation agriculture and conventional tillage. Where biological soil conservation measures cannot be done to the full effect, particularly in areas of high intensity storms, or where there are periods of poor crop cover, earth works (physical control measures) can provide surface protection by holding water to give it time to soak through the surface. Such physical conservation measures include the construction of contour bunds, terraces and ridges (Ibraimo and Munguambe, 2007).

Conservation agriculture includes tillage systems that create an environment possible for the growing crop and that optimize conservation of soil and water resources (Veenstra *et al*., 2006 and Baker *et al*., (2002). This involves optimum retention of residues on the soil surface and the utilization of herbicides to control weeds where tillage is not or cannot be performed. The principle is to minimize the concentration of runoff volume and to slow down the runoff velocity, allowing the water more time to soak into the soil, limiting its capacity to transport soil particles and diminishing its ability to cause scour erosion (Bwalya, 1999). Govaerts *et al*., (2005) reported that in a field experiment involving small scale farmers in Elbatan, Mexico yield improvement was observed through zero tillage, appropriate rotations and retention of sufficient residues (average maize and wheat yield of 5285 and 5591 kg ha−1), compared to the common practices of heavy tillage before seeding, monocropping and crop residue removal (average maize and wheat yield of 3570 and 4414 kg ha−1). Conventional tillage with or without residue incorporation resulted in intermediate yields. Zero tillage without residue drastically reduced yields, except in the case of continuous wheat which, although not high yielding, still performed better than the other treatments with zero tillage and residue removal. Zero tillage treatments with partial residue removal gave yields equivalent to treatments with full residue retention (average maize and wheat yield of 5868 and 5250 kg ha^{-1}). Raised-bed cultivation systems allow both dramatic reductions in tillage and opportunities to retain crop residues on the soil surface. Permanent bed treatments combined with rotation and residue retention yielded the same as the zero tillage treatments, with the advantage that more varied weeding and fertilizer application practices are possible. It is important small-scale farmers have access to, and are trained in the use of these technologies. Conventional tillage improved soil aeration, reduced the evaporation of the soil moisture and stimulated the decomposition of organic matter, thus making nutrients available. Lal, (2006) reported that enhancing soil quality and agronomic productivity per unit area through improvement in soil organic carbon pool show that crop yields were increased by 20–70 kg ha^{-1} for wheat, 10–50 kg ha^{-1} for rice, and 30–300 kg ha^{-1} for maize with every 1Mg ha^{-1} increase in soil organic carbon pool in the root zone. Adoption of recommended management practices on agricultural lands and degraded soils would enhance soil quality including the available water holding capacity, cation exchange capacity, soil aggregation, and susceptibility to crusting and erosion. Increase in soil organic carbon pool by 1Mg ha^{-1} y^{-1} can increase food grain production by 32 million Mg y^{-1} in developing countries (Lal, 2006).

Deep tillage using tine implements increases the soil moisture holding capacity through increased porosity, to enhance infiltration rates and to reduce the surface runoff by providing surface micro-relief or roughness. Deep tillage allows roots proliferation to exploit soil water and nutrients at deep horizons and hence increasing crop performance, for example in Babati district of Tanzania maize yield was 2000 kg/ha in the 1995/96 harvest up from 900 kg/ha of conventionally ploughed land (Mati, 2006; Hatibu and Mahoo, 2000). The chisel-ploughed and deep-tilled treatments reduced the volume of runoff by 36 to 53 percent compared to the control, and when compost was added, the reduction increased substantially to 74 to 91 percent (Jeremy and Balousek, 2003)

Baron *et al*., (2003) reported that harvesting rainwater in agriculture demonstrated the potential of doubling food production by 100% compared to the 10% increase from irrigation in Dodoma region in Tanzania, a region that faced food security problems over the years due to drought and strongly argues that to curb further food deficits rainwater harvesting need to be promoted since already rainfed agriculture is practiced on over 80% of the world's agricultural land area, and generates 65-70% of the world's staple foods (Mati *et al*., 2000). Rainwater harvesting increases food production and hence, forms the foundation of many development projects in promoting agriculture and land management. For instance maize yield can be tripled with rainwater harvesting through conservation agriculture because the technique minimizes the risk of crop failure during droughts, intra seasonal droughts and floods (Baron *et al*., 2003).

Ngigi, (2003) reported that *fanya juu* terraces which were previously used with diversion/cut-off drains for soil conservation especially in Machakos and Kitui counties of Kenya, have been adopted for rainwater harvesting. They were modified by constructing planting pits mainly for bananas and tied ridges (check dams) for controlling the runoff. The outlet was blocked to ensure as much runoff as possible is retained while spillways were provided to discharge excess runoff, which was diverted into the lower terraces. Runoff spreading has also been accomplished by contour bunds in Laikipia County. The terrace channels collect and store runoff from various catchments including footpaths and road drainage. The stored runoff seeps slowly into lower terraces ensuring adequate moisture for crops grown between the terrace channels. Parts of this work reported here indicate that there is moisture variability created by terracing. According to Kiggundu (2002), in Southern Uganda, a similar system has been adopted, in which contour ridges/bunds, (shallow *fanya juu* terraces) tied at regular intervals are used in banana plantations. The runoff from hilly grazing lands is distributed into the banana plantations by contour ridges. Agroforestry (for firewood and fodder) is also incorporated, with trees planted on the lower side and napier or giant tanzania grass along the ridges. This system has greatly improved the yield of the bananas and has enhanced zero grazing of dairy cows. Contour ridges and infiltration trenches have also been adopted for soil erosion control, revival of wetlands and improvement in pasture quality (Mugerwa, 2007). The infiltration trenches are dug at specified intervals according to the land slope and tied at regularly intervals to allow water retention and subsequent infiltration. The soil is either thrown upward (*fanya juu*) or downwards *(fanya chini)* and stabilizing grass or fodder crops planted. Runoff from uphill catchments is diverted into these contour ditches (infiltration trenches) to increase soil moisture. In eastern part of Sudan, a traditional system of harvesting rainwater in ‘‘terraces’’ is widely practiced (Critchley and Gowing, 2012). It consists of earthen bunds with wing walls which impound water to depths of at least 50 cm on which sorghum is planted. Within the main bund there may be smaller similar bunds which impound less runoff on which planting is done. Trials using trapezoidal bunds, terraces and semi-circular bunds carried out by the Baringo Pilot Semi-Arid Area Project (BPSAAP) in Kenya’s Baringo County with an annual average rainfall about 650 reported sorghum yields between 2.3 and 3.4 times greater than on adjacent control plots and cowpea yields between 3.5 and 7.7 times higher. (Critchley and Gowing, 2012) reported that a project in Niger to rehabilitate degraded areas using demi-lunes (semi circular bunds) water harvesting techniques, resulted in a production of about 250 kilograms of sorghum per hectare in poor rainfall years and up to 600 kg/ha in normal years, on fields where rain fed agriculture was not feasible at all.

Findings by (Mupangwa *et al*., 2006) indicated that rainwater harvesting improved water infiltration, extend duration of soil moisture availability in the soil and store surface and sub-surface runoff for later use. The results showed that infiltration pits significantly capture rainfall and runoff water. Water captured by the pits replenished soil water on the up and down slopes of the pit. The amount of water in the top 30 cm depth at the end of dry season was negligible while there was a lot of variation in amount of water within the 90 cm depth. Improved tied ridges collected more water than the conventionally ploughed plots. Significant observations made were that sorghum and sunflower crops under ridges showed less moisture stress than crops grown on flat plots. These studies also showed positive interaction effect of either fertilizer or manure with soil moisture conservation on crop yield. Mulch ripping gave higher soil moisture in the topsoil especially at the beginning of the cropping season. Mulching protected the soil from erosion and promoted infiltration. The potential of rain water harvesting in providing water as supplement to increase crop yield and reduce the risk of crop failure is very high. Enhancing and stabilizing the crop yield of subsistence farmer will give them the incentive to invest more in other soil nutrient enhancements (Mupangwa *et al*., 2006).

According to Barron, (2009) to meet an increased food demand with less use of water and land in these regions, there is need for farming systems that provide more yields per unit land area and unit water Improvements in on-farm water and soil fertility management through water harvesting may be key to up-grading smallholder farming systems in dry sub-humid and semi-arid Sub-Sahara Africa (SSA) whose yield levels are usually less than one ton per hectare which are 3-5 times lower than potential levels obtained by commercial farmers and researchers under similar agro-hydrological conditions. Barron (2009) attributed the low yields to the poor crop water availability due to variable rainfall, losses in on-farm water balance and inherently low soil nutrient levels. The same is acknowledged by Gichuki *et al.*, (1993) who stated that in arid and semi arid lands in Kenya, crop yields can be significantly increased by increasing the crops growing period by availing moisture through rainwater harvesting. In order to improve the livelihoods of the dryland population there is need for improved farming methods that will include, use of suitable crop varieties, timely planting and soil management. In addition as climatic conditions put high demands on water resources, it means using the limited amount of rainfall as efficiently as possible by increasing soil water content, supply and retention (Hatibu and Mahoo, (2000). Terracing, though labour intensive is one of the techniques used to prevent runoff and increase soil water content, where rainfall is insufficient to meet the crops' water demand (Duveskog *et al.*, 2003). Terracing help to redistribute moisture and therefore creating zones of varying moisture levels, my study sort to use this variability of moisture in the terraced field including that which is harvested in the terrace ditch to develop an appropriate cropping pattern that can maximally utilize the harvested water according to the moisture demand of the crops.

Report by Ngigi (2003), indicate that rain water harvesting has the potential for addressing temporal and spatial water scarcity for domestic, crop production, livestock development, environmental management and overall water resource management in semi arid savannah environments. The potential however has not been exploited despite the occurrence of persistent low agricultural production and food shortage in Sub-Saharan Africa. In the dry, semi-arid temperate areas, such as Central West Asia and North Africa, seasonal rainfall of only 300–400mm is enough to produce as much as 4 tonnes per hectare (t/ha) of wheat grain because precipitation falls during the cool winter growing season and the growing season is lengthen (UNEG, 2011).

Many parts of Sub-Saharan Africa (SSA) could greatly improve food security through rainwater harvesting and management, which aim to supply the deficit moisture between rainfall and evapotranspiration during the crop's growing season. Where rainwater harvesting and management is used for supplemental irrigation, the deficit is maintained by supplying water to the crops at the critical growth stages as a tactical measure during drought spells. This water is used to stabilize production with the aim of maximizing the net income per unit water used when water supplies are limiting. The farmer's goal therefore should be to maximize net income per unit water used rather than per land (Fereres and Soriano, 2006; Oweis and Hachum, 2009). Some experts regard irrigation as the only viable method of agricultural production in the ASAL (Ngigi, 2003), but history has proved otherwise especially for small scale farming systems. The promotion of rainwater harvesting and management should take into consideration the perceived low rates of financial investments, especially in runoff farming, compared to irrigated agriculture. Rainwater harvesting and management minimizes some of the problems associated with irrigation such as competition for water between various uses and users, low water use efficiency, and environmental degradation. It is a simple, cheap and environmentally friendly technology, which can be easily managed with limited technical skills. The technology can also be integrated with many land use system, hence it is appropriate for local socio-cultural, economic and biophysical conditions. Furthermore, there are many traditional water management techniques still being used to make optimal use of available rainfall (LEISA, 1998). There is a need for a more efficient capture and use of the scarce water resources in arid and semi-arid areas. An optimization of the rainfall management, through water harvesting in sustainable and integrated production systems can contribute to improving the small-scale farmers' livelihood by upgrading the rainfed agriculture production (Wallace, 2000). The main objective of my study was to use the moisture and nutrient variability within the terrace to come up with a suitable cropping pattern by placing the higher moisture demanding crops where moisture is abundant and those with low moisture demand in areas with less moisture, this will result in maximum utilization of the water harvested in the terraced field, more so in the drylands where moisture is most deficient.

2.5 Terracing and its effects on soil moisture and nutrient variability

A terrace is an earth embankment, or a combination of ridge and channel constructed across the field slope. Terraces are soil and water conservation structures designed to control erosion by reducing the slope length of the cultivated land and to increase water infiltration by retaining runoff. They are constructed along the contour either through excavation, by leaving unploughed grass strips or by planting grass strips. When the terrace is constructed by excavation, the excavated soil is used to form an embankment that is compacted so as to retain runoff without toppling over

(Thomas, 1997). The depth and width of the trench will be dictated by the percentage slope of the farm. In Kenya the recommended ditch dimension for *fanya juu* terrace is 60cm wide and 60cm deep, though because of lack of maintenance the terrace ditch is lesser in depth due to silting.

Terracing is one of the oldest means of significantly reducing soil loss due to water erosion if well planned, correctly constructed and properly maintained (Dorren and Rey, 2004). The principle objective of terracing is to reduce runoff and soil loss but it also contributes to increasing the soil moisture content through improved infiltration. Results obtained in Paraná, Brazil showed that terracing reduced soil losses by half, independently of the used cultivation system. Chow *et al*., (1999) observed dramatic decreases in soil loss, from an average of 20 tonnes per hectare, to less than one tonne per hectare by terracing sloping fields in combination with constructing grassed waterways and contour planting of potatoes. Runoff was reduced by as much as 25% of the total growing season rainfall, making it more available to the crop. Similar results were obtained by Doreen and Rey (2004) who showed that in Malaysia a slope of 35 degrees covered with peppers had a soil loss of 63 t/ha/yr, while soil loss on the same slope with terraces and with identical vegetation cover, was 1.4 t/ha/yr. Likewise a study by (Kinoti, 2012; Kinoti and Gachene, 1999) observed that stolons of donkey, creeping signal and tall signal grasses not only stabilized the terrace embankment but also aided in trapping and deposition of sediments above the strips. This means that the efficiency of terraces can be increased by applying additional conservation practices such as appropriate land preparation (contour ploughing), appropriate cultivation of crops (strip cropping), permanent cover maintenance, application of manure and fertilizer to the soil (Dorren and Rey, 2004). There is also need to develop an appropriate cropping pattern that will utilize the harvested water as well as the fertile soil at the deposition zone in the terraced field.

Understanding the effects of agricultural terraces in soil physical properties is fundamental for improving resource use efficiency, such as water and nitrogen fertilizer. Knowledge on the effect of agricultural terraces brings into focus a valuable tool for precision agriculture and leads to greater economy at landowner and state levels. Terracing is a necessary practice in avoiding soil and nutrient losses in sloping areas. Terraces increase temporary surface moisture storage capacity, encourage infiltration, and conserve more water for plant growth. Field research has indicated greater soil moisture content throughout the root zone in the terrace channel when compared to the in-between channel intervals. Zoca *et al.*, (2012), argued that the greater water content in the channel can lead to a better efficiency in the use of nitrogen, as its absorption by the root via mass flux is dependent on water and therefore facilitated by greater water availability. However, the gradient of change of soil water and physical properties across the soil profile as affected by terraces is unknown. Given the wide use of terraces and the increasing adoption of precision agriculture and variable rate nitrogen application, the knowledge on the distribution of soil water and physical properties as affected by terracing is critical (Zoca *et al.*, 2012). One of the objectives of this study was to assess the effect on terracing on moisture and nutrient variability in the terraced farm for the purpose of taking advantage of the spatial variability to improve crop production.

In a field experiment carried out in Pacucha Peru, Posthumus and De Graaff (2005) reported that farmers practiced terracing for the purpose of preventing soil loss and to improve cropping conditions on their fields which were not only in steep slopes but also because their farm had many stones rendering them unproductive. Due to the improved growing conditions caused by terracing, the farmers managed to sow the crops more densely and in addition they cultivated high-value crops like vegetables, potatoes and improved maize varieties. This resulted in higher productivity of 50 per cent, or about 20–40 per cent cultivable area (Graaff and Dwiwarsito, 1990). Often the yields become more sustainable as well, justifying terracing both physically and socially. They also observed that, the steeper and more degraded the field the more pronounced the positive effect of terracing on productivity. However, when farmers did not take advantage of the improved conditions, bench terraces became unprofitable. Construction of bench terraces was thus not enough, but had to be combined with extension and introduction of improved agricultural practices like sowing techniques, fertilization and crop rotations. Bench terraces enabled cropping activities on fields that were otherwise left out of cultivation because of slope steepness, stone abundance or more erodible soil type. Terracing greatly reduced the risk of crop failure during dry spells, due to the water conserving effect. In Uganda, a study on terrace development applied as a water harvesting technology for stable new rice for Africa (NERICA) production revealed that terrace development was efficient in terms of rainfall catchment which led to increased volumetric water content and rice yield. Goto *et al*., (2012) added that high yields were reported in terraced farms, with the non terraced farms with the least yields. The average yield for the terraced farms was 1713 Kg/ha, approximately 3 times higher than that of the control (615 Kg/ha). In addition, the average increasing rate in volumetric water (VWC) content after rainfall was four times higher, with terraced plots recording 9.1 and non-terraced 1.9%. These results above indicate that terracing can be an effective water harvesting technology especially where there is variability in rainfall. It was also revealed that terrace development decrease the number of missing rice plants by reducing the influence of soil erosion on sloppy fields (Goto *et al*., 2012).

In a study on the role of farmland terracing in maintaining soil fertility, conducted in the Lake May Bar Watershed in Wello, Northern Ethiopia, it was reported that terracing brought remarkable physical changes such as terrain modification soil depth improvement and bench terrace formation (Damene *et al.,* 2012). The report also indicated that terracing reduced soil and nutrient loss through water erosion and that due to erosion and leaching of soluble salts from the upper slope and accumulation at the foot slope, soil pH and exchangeable bases increased with decrease in slope. The pH increased from 6.5 to 7.0 while exchangeable Na+ 0.22 to 0.40 (Cmol /kg) and K+ 0.38 to 0.54 (Cmol/kg. Soil texture was also significantly different across the terrain, the upper slope position had higher ($P \leq 0.01$) sand (24%) than the lower slope position with 19%. Clay content was 45% in the lower terrace position against 37% in the upper slope position. The mean clay difference varied from 5 to 6%. This difference in texture between slope positions is an indication that effect of erosion persisted for longer period after terracing. Damene *et al.,* (2012) further reported that there was poor crop performance at the lower terrain position due to water logging and recommended that crops sensitive to water logging be excluded from the lower slope position or the excess water be drained regularly to alleviate the situation and suggested that high moisture demanding crops be planted in the lower zone to utilize the excess moisture. The above findings could imply that slope position influences nutrients and moisture status, and use of terraces and an appropriate choice of cropping pattern that will maximally utilize the harvested water in the ditch will improve soil productivity. In conclusion, Damene *et al.,* (2012) argued that though farmland terracing contributed greatly to the reduction of soil erosion and nutrient loss by water, terracing alone was unlikely to improve soil fertility and crop productivity. Terracing should therefore be supplemented by fertilizer (organic or inorganic) use, suitable crops varieties, other soil and water conservation techniques like contour furrowing and zero tillage.

In semi-arid regions, topographic differences are responsible for much of the variability in soil fertility and crop yield. The crop demand for nutrients such as nitrogen and phosphorus may vary across the landscape, largely as a function of differences in water availability and the level of nutrients. Schepers and Raun (2008) found that greater moisture levels, higher infiltration, and subsequent greater vegetation growth of the lower slope positions, along with the redistribution of soil to lower slope segments, resulted in increased organic carbon (OC) and available nitrogen and phosphorus content at these segments.

A study carried out in Taiwan by Chun-Chih *et al.,* (2004), on the relationships between soil properties and slope position, showed that organic carbon, available nitrogen, extractable iron (Fe) and exchangeable sodium (Na) were highest on the summit, while pH, available phosphorus (P), exchangeable calcium (Ca) and magnesium (Mg) were significantly higher on the foot slope at 0–5-cm soils. Similar patterns were observed at subsurface 5–15-cm depth soils. The organic carbon (OC) increased with increasing altitude, probably due to the quality of litter fall and lower rate of decomposition in the summit forest. These results confirmed that slope factor was involved in the transport and accumulation of solutes resulting in higher pH, exchangeable calcium and magnesium, lower organic carbon, available nitrogen and potassium, extractable zinc in the depositional areas of foot slope.

The findings by Ovuka, (2000), on soil nutrient changes along slope transects in Murang'a County, Kenya also showed that soil nutrient status differed depending on slope position and land management. Significant differences ($P \leq 0.01$) depending on slope position were found in potassium, available phosphorus, total nitrogen and carbon. Ovuka (2000) observed that the differences in nutrient status between slope base and other parts of the slopes could be as high as 80%. Where land management, including soil and water conservation structures like terraces, were used there was less pronounced differences in slope position. The importance of soil erosion prevention was also confirmed by enrichment ratio, where the results recorded one and half times higher nutrients levels on average in eroded sediment compared to in situ soil. With intensive land use and limited access to fertilisers, Ovuka (2000) recommended the use of soil and water conservation structures especially in steep slopes to prevent soil and nutrient erosion. The results indicated that, land management had an important role on the nutrient status and on improved crop yields. Amare *et al.*,(2013) in a study to asess soil properties and crop yields in Anjeni watershed in central Ethiopia reported higher mean yields of both maize and wheat at the deposition zone (lower slope position) followed by middle zone, while the lowest value was obtained from the loss zone (upper slope position). The same was echoed by Ovuka (2000) and Alemahyu (2007) who observed that there was 1.5 times higher nutrient levels on average in eroded sediment compared to in situ soil. Aung *et al.,* (2013) reported that differences were substantial in yield components parameters and grain yield depending on toposequence position. Grain yields in the lower fields of both rice cascades were higher than other field positions in both fertilized and unfertilized fields. The grain yields were significantly related with surface water amonium (NH4) concentration, TN content, sand and silt content of soil. The larger toposequential differences in crop yield require different field specific management practices for each slope position in order to improve rice production in this watershed area (Aung *et al*., 2013).

The study by Temesgen, *et al.,* (2012) indicated that adoption of soil conservation structures (SCS) especially terraces was low in the high rainfall areas of Ethiopia. The farmers complained that the terraces reduced crop yield due to among other things water-logging behind the structures and soil erosion following breaching of structures. To tackle this loss in crop production, *fanya juu* terraces were intergrated with other conservation measures and practices, conservation tillage involving contour ploughing was introduced. The intevention resulted not only in reduced surface runoff and waterlogging, but also increased grain yields of wheat and tef by 35 and 10 %, respectively. Two objectives of this study evaluated the effect of terracing on nutrient variability and the effect this has on crop performance as well as the effect of moisture variability in a terraced field on crop performance. This was aimed at identifying a cropping pattern that would improve the water and nutrient productivity of dryland agriculture. The hypothesis was that water harvested in the terrace ditch would lead to increased lateral seepage which in turn would influence crop performance depending on the position the crop is planted in respect to the terrace ditch and terrace embankment.

2.6 Terrace construction and maintenance

Terraces need regular maintenance to continue to function well. Regular inspections and general observations during the course of seasonal field operations and after large runoff events will help point out problems before disastrous failure occurs and gullies form. Erosion by water, wind, and tillage wears the ridge down and deposits sediment in the channel, decreasing the effective ridge height and channel capacity. They can also be damaged by machinery, animals and settling. Terrace maintenance restores capacity by removing sediment from the channel and rebuilding ridge height. Terraces should be considered only a part of an overall erosion control plan. Other conservation farming methods, like residue maintenance not only compliments erosion control structures but have also been found to be environmentally sound (Powell and McVeigh, 2004). In Kenya terrace construction is acceptable in regions where farmers have appreciated the benefits of terracing, for the purpose of soil conservation although their maintenance is still a challenge. Most excavated terraces are therefore not maintained and usually end up silted and not harvesting much water.

Terraces may reduce soil erosion and increase production but they should also provide sufficient financial gains at farm level. Anschütz *et al.,* (2003) argued that the costs and benefits of water harvesting should be balanced, whereas there can be benefits in yields of 50 to 100% in years of average rainfall depending on the system used, soil type and husbandry, there is a cost that comes with the excavation and maintaining of the soil and water conservation structures as the labour requirements are high. In addition most water harvesting structures are constructed in the dry season when food availability is low and farmers are forced to engage in other income generating activities to meet their families' needs. The farmers are therefore often engaged in other activities, like cattle herding or wage labour in plantations or in urban areas and with children going to school family labour may not be readily available for the excavation of the soil and water structures. In Kenya lack of training (30%), pest and diseases (14%), lack of finance and labour were identified as the major contributing factors influencing adoption (Gachene *et al,* 2015 and Mutuma *et al.,* 2015). Termites were reported to destroy both live crops and crop residues left on the farm for the purposes of soil and water conservation. Similarly social capital measures were identified as determinants of investment in soil conservation (Nyangena, 2008). In a survey carried out in Meru, Machakos and Kiambu counties of Kenya indicated that several dimensions of social capital were very important both at the level of the individual farmer and at the community level. Of particular importance were good infrastructure which reduced transportation costs and facilitated market access, security of tenure and several dimensions of social capital that appear to correlate with the ability to work together in associations, to trust each other and to spread information.

In a field study to determine the cost-benefit analysis for terracing in Pacucha, Peru, Posthumus and De Graaff (2004) established that the major costs of terracing were labour inputs which most cases were provided by family members. The family labour is often divided between off-farm jobs and farming and household activities and is thus limited. In addition the extent to which family members were involved in off-farm work determined their availability for construction work and the opportunity costs of their labour. In that study they established that bench terracing including water ways on moderately steep slopes(about 30%) required about 700 man-days per ha, meaning that that for half an hectare one household member would be fully employed for more than a year. They also observed that farm size and capital assets had an important influence on the ability of the farmer to invest in the construction of terraces (Posthumus and De Graaff, 2004). A study on the costs benefit analysis of adoption of soil and water conservation in Kenya, carried out in Murang'a County revealed that establishing of terraces was relatively expensive as reported by farmers

(Atampurge, 2014). The cost of establishing was pegged on the slope and stability of the soil. Based on farm level data, 60 to a maximum of 180 man days per hectare were required to establish a bench terrace. On average family labour used per hectare was 60 days with a maximum of 180 days and 9 days for maintenance. On average, a Man-day (MD) was valued at Kshs. 470 hence giving an estimate cost of Kshs. 28,200 for 60 days and Kshs. 84,600/ha (Nyangena and Köhlin, 2008). Terrace maintenance was cheaper (11% of establishment costs) than construction (Atampurge, 2014; Atampurge, 2014; Burrow, 2014). Lack of immediate returns to investment and high labour intensity required for construction are some of the reasons for inconsistent adoption trends (Shiene, 2012). In Ethiopia, although a section of farmers appreciated the benefits of terracing improving crop productivity, others rejected complaining of intensive labour required to construct and maintain and their observation that terracing caused water logging at the lower terrace position affected crop yields (Alemaheyu, 2007). Alemaheyu concluded that to improve the efficiency of terracing including immediate returns to investment, there was need to promote terrace maintenance and appropriate cropping pattern that will maximally utilize the harvested water. In Yemen however in addition to the high cost of terrace establishment and maintenance, the problem of non maintenance was associated with land tenure and other socio economic factors.

A study by Hassan *et al.*, (2000) on the impact of land tenure and other socio economic factors on mountain terrace maintenance, found out that farms which were cultivated by the land owners had maintained terraces while those cultivated by tenants or on public land were left to deteriorate, an observation that was linked to unclear responsibility between owner and tenant coupled with lack of incentives by the government and weak local institutions. In Rwanda terracing have been used for decades as effective soil conservation technologies as they help reduce soil loss and silting up of the fields despite arguments that terraces are high in labour intensity, time consuming in regular inspection, high consumption of scarce farmlands and large amounts of construction materials required (RoR, 2010). Rising demands for food and uncertainties about climate change call for a paradigm shift in water management with a stronger focus on rainfed agriculture.

In a study to assess the costs and benefits of bench terraces, grass strips and *fanya juu* terraces in west Usambara highlands in Tanzania, Tenge *et al.,* (2005), reported that, labour was found to be the major cost item in implementing soil and water conservation measures and is higher with bench terraces than with *fanya juu* and grass strips. The results also showed that the costs of establishing the three soil and water conservation measures exceeded the returns in the initial 2 years. However, in the long term, the three conservation measures were profitable to farmers, as there were significant increase of maize yields by 45% and 85% for beans. Tenge *et al.,* (2005), also clearly established that cross-slope barriers alone did not increase crop yields unless they were integrated with other practices such as manure and fertilizer use, timely planting and suitable seed varieties.

The high investment costs and the initial negative returns were found to be the main hindrances to adoption and maintenance of soil and water conservation structures by small holder farmers. To counter this Tenge *et al.,* (2005), recommended that there was need to gradually invest in the structures and introduce high value crops that would give better returns to investment in a shorter period. The promotion of dairy cattle under zero grazing system was floated as an option to increase the adoption of soil and water conservation measures because of the high benefits from grasses used to stabilise the structures (Tenge *et al,* 2005). Apart from improving yields, the implementation and maintenance of soil and water conservation measures in the long run will have economic, ecological and social benefits as shown in (Appendix: 1).The fourth objective of this study was to determine the profitability of maize and bean production under different cropping patterns in a terrace and maintained farm vis a vis and the farmer’s practice where the terrace is not maintained and make recommendation for use by farmers.

2.7 Cropping pattern

A cropping pattern is the sequence and spatial arrangement of crops on a given piece of land, it means the production in an area under various crops at a point of time. Cropping pattern is a dynamic concept as no cropping pattern can be said to be ideal for a particular region all times. It changes in space and time with a view to meet the crops' requirements and is governed largely by the physical as well as cultural and technological factors (Lahu, 2012). Cropping patterns include mixed farming, multiple cropping, sole cropping, monoculture and crop rotation. Weather, terrain, topography, slope, soil quality and availability of water play a decisive role in determining the type of cropping pattern. These cropping patterns have to be evolved for the realization of potential production levels through efficient use of available resources (Lahu and Dhanaji, 2010). Arif and Malik (2009) reported on the evaluation of cropping for three years (2003-2006) in Pothwar plateau in three location representing high, medium and low rainfall conditions. The economic analysis revealed the highest gross and net benefits for sunflower + mung bean based cropping pattern in high rainfall zone (54077 and 34738.00 ha^{-1}), respectively. In the medium and low rainfall areas groundnuts based cropping patterns had the highest benefits. The marginal rates of returns were highest in canola based cropping pattern at all locations (220.91 to 341.60%). Arif and Malik (2009) further reported that fallow wheat cropping pattern showed promising marginal rate of returns under both high and low rainfall conditions. Good performance was well evident for groundnut and canola based cropping patterns at all locations in terms of soil moisture, benefit cost ratio, net returns and marginal rates of returns. The results revealed that rainfall and available soil moisture are critical factors in determining the suitable cropping patterns and choice of crop. It is therefore, necessary to bring the cropping patterns in harmony with not only the rainfall patterns but also the nutrient availability in rainfed areas for improved crop yields as well as for the optimization of the limited resources. The improved cropping patterns on long term basis at field level provide effective means for soil water conservation and utilization to get sustainable crop yields (Arif and Malik 2009). Damene *et al*., (2012) argued that though terracing contributed to reducing soil erosion, it also had negative impacts on crops sensitive to certain effects, such as water-logging with respect to wheat, which had very low yield (biomass and grain) of over 50% lower than the average values. The same observation was made by (Olgun *et al*., 2008; Ghobadi and Ghobadi 2010), who reported that structures like level bund, level terraces and level *fanya Juu* resulted in water-logging problems at lower terrain positions, critically limiting wheat yields. This observation calls for specific management of each terrace slope position so as to make the best of the nutrient and moisture variability. Sherrod *et al.,* (2014) revealed that understanding the soil's physical and chemical properties and their relationship to soil moisture is important for better soil-management decisions since soil properties have effect on crop yields. This understanding would allow producers and managers to reduce risk associated with dryland cropping. This study also investigated the effect of terracing on moisture and nutrient variability and the effect these variabilities have on crop performance with the aim of coming up with a suitable cropping pattern that will take into account the moisture and nutrient demands of the crops for improved production in drylands. In Mutoko, northern Zimbabwe, a study was done on farmer's fields to investigate the small spatial concentrations of moisture and nutrients. Simon *et al.,* (1995) reported that ten farms were surveyed in detail for crop development, soil type and management history. The results were then used to develop suitable cropping patterns which farmers used to increase and sustain productivity. In Kenya though knowledge on spatial variability of moisture and nutrients especially in terraced farms is known, little attention has been given on using these variablities to the advantage of the farmer by selecting suitable cropping patterns for the dryland regions of Kenya. This study investigated five different cropping patterns for the efficient utilization of soil moisture and nutrients and their profitability under rain fed conditions in terraced fields for promotion for use by farmers.

2.8 Research gaps

Terracing has been promoted for the control of soil erosion and to regulate and discharge excess runoff, however the potential for terrace ditches to harvest rainwater and improve moisture infiltration and storage for crop growth has not been fully investigated. Gachene *et al.,* (2011), in a field experiment in Machakos County, established that there was good perfomance of crop next to the terrace ditch while the crop in the middle position was suffering from moisture stress. In addition reports by Biamah (2007), Alemaheyu, (2007) and Damene *et al.,* (2012) indicate that there were likely to be incidences of water logging and poor crop performance in the lower terrace position. The main hypothesis of this study was that maintaining terrace ditch will hold runoff which through would improve crop performance within the terraced area. On the other hand there have been studies on spatial variability of yield, crop growth performance and soil fertility (Wezel *et al*., 2002 and Homma *et al.,* 2003), but very few studies have been done on sediment- inducing spatial variation in soil properties and crop yield at different slope positions. The farmers therefore, have continued to grow their crops in terracced fields without taking into account the most appropriate cropping pattern that will give them maximum benefits from the harvested water and nutrient accumulation in the different slope positions. Zoca *et al.,* (2012), studied how soil moisture, physical impedance and bulk density, varied with increasing distances from terrace. The rationale was that the knowledge of soil physical parameters distribution across terraces will help site-specific crop management via variable-rate application of fertilizers in precision agriculture; thus resulting in lower production costs and higher nutrient use efficiency for Oklahoma producers. The results indicated that water in the channel led to better efficiency in nitrogen uptake by the crop. However the gradient of change of soil water and physical properties across the soil profile as affected by terraces in Oklahoma was unknown, like wise in Kenya the same has not been researched on. Given the importance of terraces and the need for adoption of precision agriculture, the knowledge on the distribution of soil water, physical properties and nutrients as affected by terracing is important. This study sought to investigate the effect of terracing on soil moisture and nutrient variability and the effect this has on crop yields so as to develop the most appropriate and profitable cropping pattern for promotion for adoption by farmers in Suswa location of Narok County.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study area

The study was carried out in Suswa Location, Narok County located in the Southwest of Kenya (Fig. 3.1). The county lies between longitudes 34°45'E and 36°00'E and latitudes 0°45'S and 2°00'S. The topography, ranges from a plateau with altitudes ranging from 1,000 - 2,350 m a.s.l. at the southern parts to mountainous landscape (3,098 m a.s.l) at the highest peak of Mau escarpment in the North (Serneels and Lambin, 2001; Jaetzold *et al.*, 2010) .

The county has five agro-climatic zones namely humid, sub-humid, semi-humid to arid and semi-arid, two-thirds of which are classified as arid and semi arid (NEMA, 2009). The county experiences bi-modal pattern of rainfall with long rains expected from mid March to June and short rains from September to November. The local variations in topography play a major role in the distribution patterns, with the highlands receiving as high as up to 2000 mm/yr. while the lower and drier areas receiving less than 500 mm/yr (Ojwang' *et al.,* 2010). The rainfall amounts on average are however too low for optimal crop yields and season to season variability is high, the resultant prolonged dry spells often lead to food and water shortages. The county experiences a wide disparity in temperatures throughout the year with mean annual temperatures varying from 10^{o}C in Mau escarpment to about 20^{o}C in the lower drier areas (NEMA, 2009; Jaetzold *et al*., 2010). Suswa area has sharp gradient and volcanic-ash soils that are vulnerable to erosion. The land is bare because of the overuse and loss of grass cover. Geomorphologically, there are pronounced cattle tracks evidence of intense runoff and flash floods during the rains (Odini *et al.,* 2015).The area is dominated by scattered acacia tree species and *Thaconathuszaw camphoratus* which is an indication of dry weather conditions and depressed rainfall amounts. The trial site (Ole Sharo) lies in GPS location 01^{o}09'16.3" E 36^{o}14'36.0" Altitude 1767m a s l, with a slope of 14% (Maina, 2013).

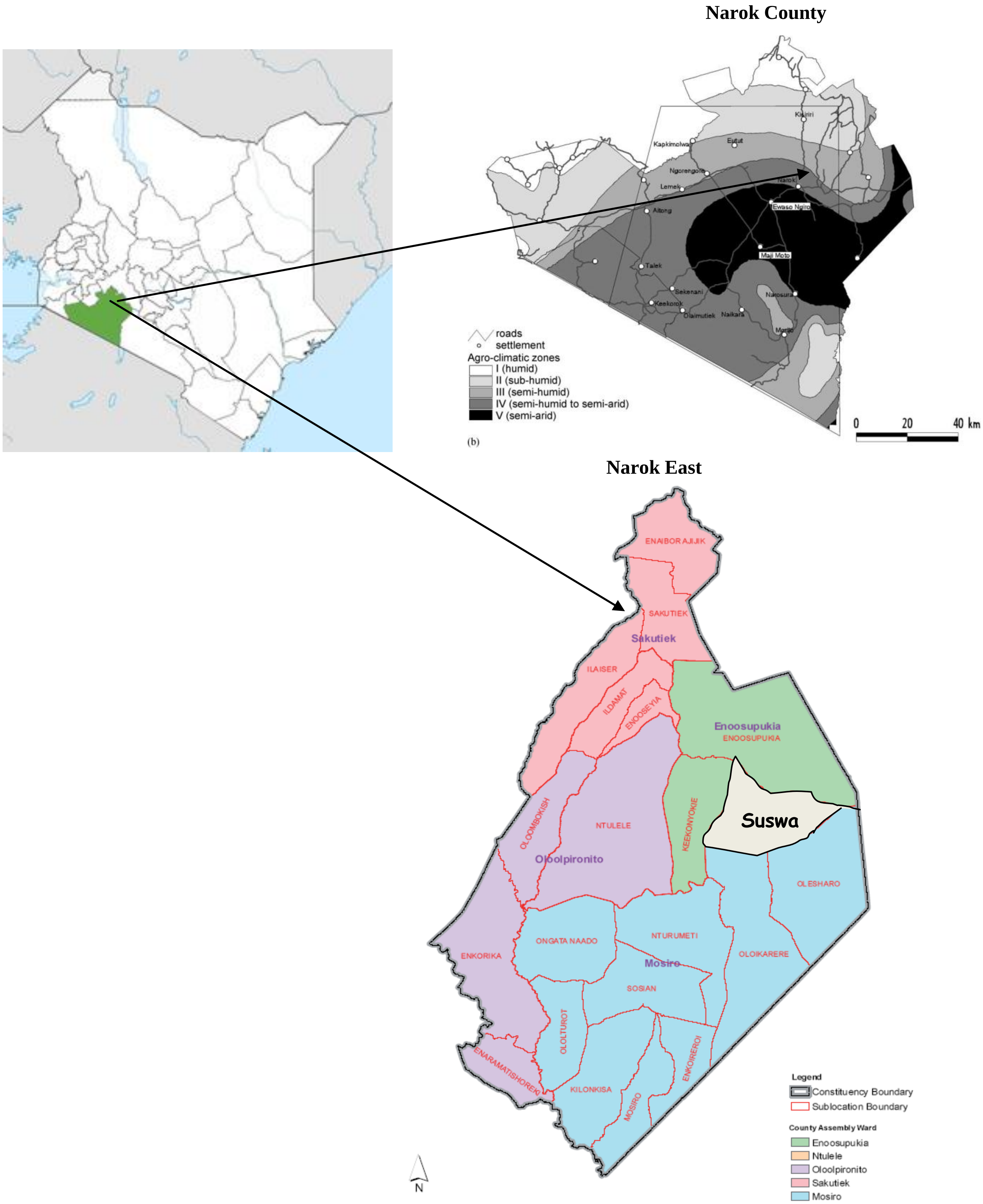

Figure 3.1: The study area in Narok County
Source: Narok District Environment Action Plan 2009-2013

3.2 Land use

Narok County has diverse land use types across all the agro ecological zones. The highlands of Narok north have large scale commercial farms with small scale mixed farming in the mid elevations. In the mid and lower parts there is a combination of pastoralism and small scale farming where soils and climate are suitable there is leased farming for commercial wheat and barley production. The north eastern part around Suswa is agro pastoral in the wetter parts and largely pastoral punctuated with cultivated patches in the drier parts. In the lowlands with unreliable rainfall there is sheep, goat, beef cattle production and bee-keeping (Maina, 2013; Jaetzold *et al.*, 2010).

Land in the high potential areas is individually owned while the rangelands are either under communal, family or group ranches, though encroachment by agricultural activities is rapidly leading to subdivision to individual holdings (GOK, 2007). The other human activities that characterize the study area are the presence of water pans for water harvesting for both human and livestock use. Suswa area is also rich in wildlife that is harnessed for the tourism and ecotourism industries.

3.3 Suswa soils

The soils in Suswa area are humic andosols, well drained, deep to very deep, dark brown, friable and smeary, sandy clay to clay, with acidic humic topsoil (Sombroek *et al.*, 1982; Jaetzold *et al.*, 2010). These soils have sand to silt clay ratio of 2:1 on average for the horizons studied (Gachene, 2014). The high silt /clay ratio, low organic matter and high bulk density have made the soils more prone to erosion leading to severe soil losses. The soils are stratified with hard pans underlain by soft clayish strata that are readily eroded (Maina, 2013).

Table 3.1 Characterization of the Suswa andosols

Horizon	**Depth (cm)**	**Average BD(g/cm^3)**	**Average %OM**	**Average Ksat(cm/h)**	**Sand**	**Clay**	**Silt**	**Texture class**
A	0-10	1.36	1.29	0.85	62.4	17.6	20	SL
BU1	10-21	1.35		0.89	70.4	7.6	22	SL
BU2	21-31	1.19		0.96	58.4	19.6	22	SL
BC	31-49				70.4	7.6	22	SL

BD=Bulk density, OM= Organic Matter, Ksat= hydraulic conductivity, SL= Sandy loam

Source: Gachene, 2014

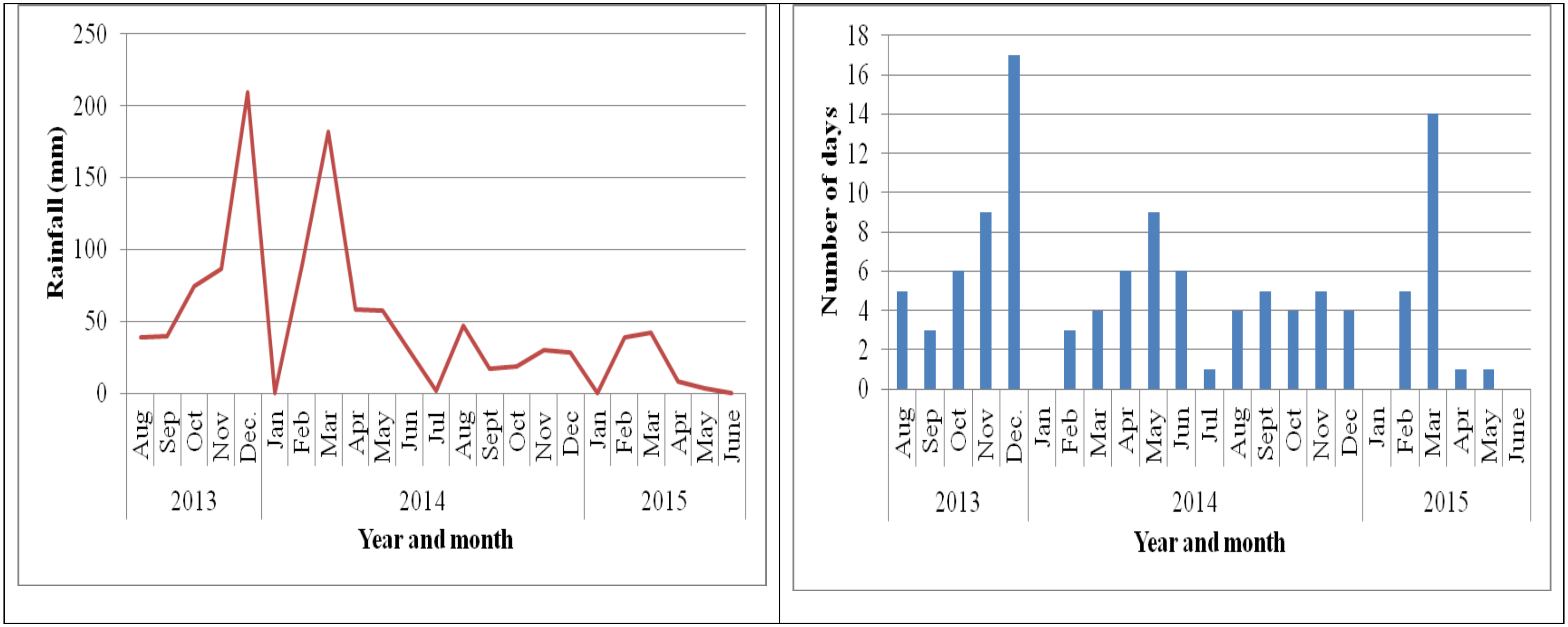

Figure 3.2: Rainfall and number of rain days during the trial period at Suswa site

3.4 Experimental layout and design

Table: 3.2 Terrace treatment arrangements

<table>
<tr><td colspan="8">Upper Terrace ditch of 60x60 cm as recommended by the Ministry of Agriculture</td></tr>
<tr><td colspan="6">Terrace ditch maintained</td><td colspan="2">Terrace ditch not maintained</td></tr>
<tr><td>Treatments</td><td>CP1</td><td>CP2</td><td>CP3</td><td colspan="2">CP5</td><td colspan="2">CP4 (control)</td></tr>
<tr><td rowspan="3">Slope direction ↓</td><td>Maize and Beans</td><td>Maize and Beans</td><td>Maize</td><td>Maize and Beans</td><td>Zone of moisture accumulation</td><td>Maize and Beans</td><td>Zone of moisture deficiency</td></tr>
<tr><td>Maize</td><td>Beans</td><td>Maize</td><td>Maize and Beans</td><td>Zone of moisture deficiency</td><td>Maize and Beans</td><td>Zone of moisture deficiency</td></tr>
<tr><td>Maize and Beans</td><td>Maize and Beans</td><td>Maize</td><td>Maize and Beans</td><td>Zone of Moisture and sediment accumulation</td><td>Maize and Beans</td><td>Zone of Moisture and sediment loss</td></tr>
<tr><td></td><td colspan="5">Maintained Terrace embankment</td><td colspan="2">Terrace embankment not maintained</td></tr>
<tr><td colspan="8">Upper Terrace ditch of 60x60 cm as recommended by the Ministry of Agriculture</td></tr>
</table>

Treatments

CP1: Maize and Bean intercrop in the upper and lower zones and sole maize in the middle
CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle
CP3: Sole maize crop in all the three zones
CP4: Farmers' practice where terrace is not maintained
CP5: Intercrop of maize and beans in upper, middle and lower zone.

The experiments were laid out in both the short and long rain seasons of 2013-2014/15, in a randominsed complete block design (RCBD) with five treatments each replicated three times as follows, (i) Cropping pattern 1(CP1) Maize and bean intercrop planted in the upper and lower slope positions within the terrace and sole maize in the middle slope position, (ii) Cropping pattern 2 (CP2) Maize and bean intercrop in the upper and lower slope position and sole bean crop in the middle slope position (iii) Cropping pattern 3 (CP3) sole maize crop in the upper, middle and lower terrace position, (iv) cropping pattern 4 (CP4), control plot where terrace was not maintained had maize and bean intercrop in all the three slope positions, (v) Cropping pattern 5 (CP5) maize and bean intercrop in all the three slope positions. The plots were arranged as indicated in figure 3.3.

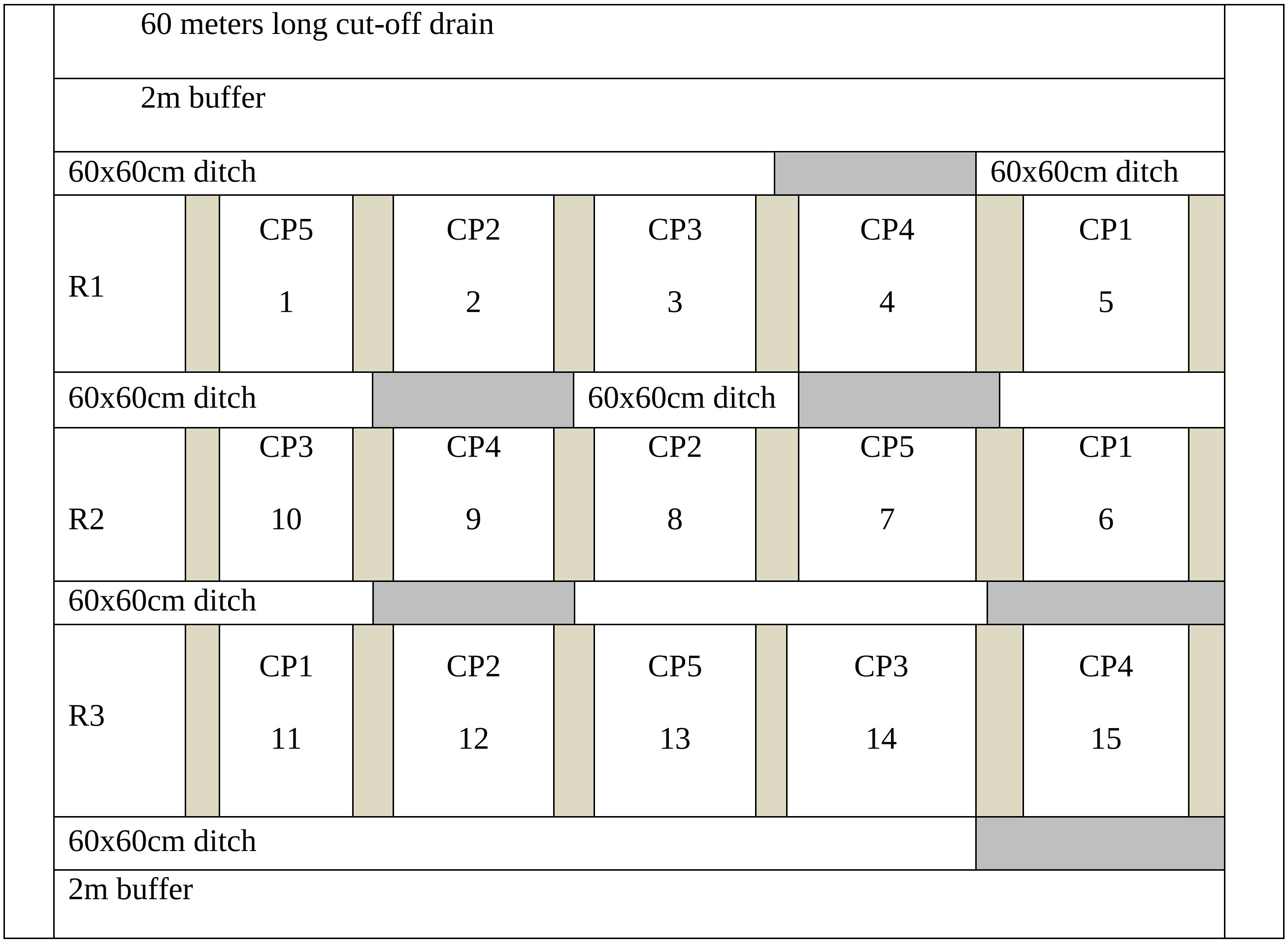

Figure 3.3 Experimental plot layout

Key:
Replications = R1…R3,
Plots numbers = 1, 2 …15
Plot treatments =CP1, CP2…CP 5,
Space between plot treatments was 1 m
Space between blocks will be the 60x60 cm *fanya Juu* terrace ditch
Plot size = 15x6 m= 90 m^2

3.5 Agronomic Practices

Maize (*Zea mays*) and beans (*Phaesolus vulgaris L.*) were used as the test crops. These crops were planted in furrows, one metre from the terrace ditch during the long and short rains of the years 2013-2014/15 in 15 x 6 m^2 plots. Maize (KH 500-33A variety) was planted at a spacing of 90 × 30 cm in pure stands while in the intercropping system at 90 × 50 cm and bean (Katumani x 56) was planted at a spacing of 45 x 15 cm as a sole crop and at 90 x 30 as an intercrop. Thinning was done to a single plant per hill for maize and two plants for the legume, four weeks after germination. In each cropping pattern, nitrogen fertilizer was applied at 50 kg N ha^{-1} (DAP 18:46:0) at planting and 50 kg N ha^{-1} (CAN 26:0:0) top dressed when maize was at knee-high. Weeding as well as pest and disease control was carried out as recommended.

3.6. Data collection and laboratory analysis

The plant, soil samples and growth parameters were collected and measured line by line from the terrace ditch to the terrace embankment. The plot was divided into five equal portions for the purpose of data analysis from the terrace ditch to embankment as follows; U=upper slope position, UM = upper middle slope position, M = middle slope position, LM= lower middle slope position and line L = lower slope position.

3.6.1. Soil moisture variability

Soil moisture distribution was monitored within the terrace throughout the growing period. The soil samples were collected by using an auger from each experimental plot at critical crop growth stages. At germination the soils were collected in the upper, middle and lower slope position, because at this stage the crop is young and the roots depth is still within the 30 cm depth. At the 9th leaf stage the soil samples were collected at 30-50 cm while at tassling stage, the soils were sampled at 50-75 cm from the upper, upper middle, middle, lower middle and lower terrace slope position.

The sampled soils were then taken to the laboratory for moisture determination using gravimetric method (Okalebo *et al.,* 2002).

3.6.2. Crop performance indicators

The crop performance was evaluated by monitoring crop height, number of leaves, leaf area index and yield in the upper, upper middle, middle, lower middle and lower slope position from the terrace ditch to the terrace embankment.

3.6.2.1 Maize plant height

The maize crop plant height was measured both and 9th leaf stage and at tussling from the base of the maize (soil level) to the top (highest point) or to the tip of the tussle by use of a folding ruler in all the experimental plots. A representative sample of five plants selected randomly was used and the average height recorded. According to Xinhua *et al* (2011), maize yield is related to maize plant height and maize yield can be predicted with plant height measurements collected during the plant critical growth stages**.**

3.6.2.1 Number of leaves in maize

The Number of leaves in maize plant was determined by counting and recording the number of leaves of five maize plants selected randomly in the upper, upper middle, middle, lower middle and lower terrace slope position in all the 15 plots with maize crop using the leaf collar method. This method determines leaf stage in corn by counting the number of leaves on a plant with visible leaf collars, beginning with the lowermost, short, rounded-tip true leaf and ending with the uppermost leaf with a visible leaf collar (Abendroth *et al*., 2011). The leaf collar is the light-colored collar-like “band” located at the base of an exposed leaf blade, near the spot where the leaf blade comes in contact with the stem of the plant

3.6.2.2 Leaf Area Index

The leaf area index (LAI) was carried out for maize plants in the 9th leaf and at tassling stage. The LAI was determined by counting the number of leaves of selected five plants in all the five slope positions and the average number of leaves per plant calculated. Then for each plant the length and the greatest width per plant is calculated. The average total leaf area per plant was estimated according to the method of Duncan and Hesketh (1968) for the maize crop.

LA=L x W x 0.75 x nL where LA is the average total leaf area per plant, L is the average leaf length, W the average greatest width 0.75 is a constant for the maize leaf area and nL is the average number of leaves per plant, therefore LAI= leaf area/land area.

3.6.2.3 Above ground biomass

Maize crop performance was further assessed by estimating the above ground plant biomass yields at tasseling stage. This biomass is comprised of structural components including stalks, leaves, tassel, husk, and cob. To estimate the above ground biomass five maize plant samples were selected randomly in all plots in the upper, upper middle, middle, lower middle and lower terrace slope position. The samples were cut at ground level after measuring the height and leaf area of green leaves. The samples were weighed using a spring balance (to the nearest 0.1kg) to determine the fresh weight (SOP, 1994). A representative sample was put in a well labelled sampling paper bags and taken to the laboratory where further fresh weight was taken. The samples were then oven dried at about 70°C till a constant weight was achieved and weighed immediately to obtain the oven dry weight of above ground biomass. Total above ground dry matter yield (kg/ha) was calculated as outlined by USDA (2009).

3.6.2.4 Number of pods in beans

Bean performance was estimated by counting and recording the number of pods with seed per plant from the terrace ditch to the embankment. Five plants were randomly selected in the upper, upper middle, middle, lower middle and lower terrace slope position in all the 12 plots with bean crop.

3.6.2.5 Crop yield

To determine the yield, five crops were selected in all the 15 plots at physiological maturity Maize on cobs were harvested and representative samples put in well labelled brown paper envelopes. The samples were shelled and the grains dried at room temperature to a moisture content of between 13-15%. The grains were then weighted to give the yield in kilograms per square meter which was later adjusted to metric tons per hectare (SOP, 1994). Bean yields were determined by randomly selecting five bean plants in each plot from the terrace ditch to the embankment. The grains were harvested at the plant physiological maturity and the beans shelled and weighed to give the yield in kilograms per square meter which was later adjusted to kilograms per hectare. Three seasons harvest was used for maize because the fourth seasons' crop did not reach physiological maturity due to a dry spell experienced between the months of April to June 2015.

3.6.3 Soil nutrient variability within terraces

3.6.3.1 Soil nutrient variability

Soil samples from the 0 - 30 cm depth from the upper, middle and lower slope position of each experimental plot were collected before and after each cropping season. The soil samples were air-dried and subsamples sieved (< 2 mm sieve) prior to physical and chemical analysis. The % organic carbon, total nitrogen (wet digestion /Kjeldahl method), soil pH, available phosphorus (Mehlich method), and potassium (Flame photometry) were determined by the procedures and methods outlined by Okalebo *et al.,* (2002). The values were compared with crop yields.

3.6.3.2 Plant nutrient uptake

Five plant samples were randomly selected in the upper, upper middle, middle, lower middle and lower terrace position in all the 15 plots. The maize plants were then cut at ground level and the samples weighed using a spring balance (to the nearest 0.1 kg) to determine the fresh weight (SOP, 1994). A representative sample was put in paper envelopes and taken immediately to the laboratory to avoid moisture loss, where the samples were oven dried at about 70^{o}C till a constant weight was achieved and weighed immediately to obtain the oven dry weight. The dried plant samples were ground and passed through a 2 mm sieve prior to chemical analysis for nutrient uptake. Total nitrogen uptake was determined by use of wet digestion /Kjeldahl method, available phosphorus by use of Mehlich method and potassium by Flame photometry method as outlined by Okalebo *et al.,* (2002).

3.6.3.3 Grain Nutrient content

For the determination of nutrient uptake in grains, a representative sample of maize on cobs were selected from all the five slope positions and put in well labelled paper envelopes and taken to the laboratory where fresh weight was taken. The samples were then shelled and the grains dried at room temperature to a moisture content of between 13-15%. The grains were ground and passed through a 2 mm sieve for total nitrogen (wet digestion /Kjeldahl method), available phosphorus (Mehlich method), and potassium (Flame photometry method) analysed as outlined by Okalebo *et al.,* (2002).

3.6.4 Gross margin analysis of maize and bean production in a terraced field

Gross margin analysis was carried out to determine the profitability of maize and beans grown in terraced farms compared to that grown on non-terraced farms and the grain yields obtained as outlined in Farm Gross Margin and Enterprise Planning Guide (2013). Gross margin analysis only focuses on the income and costs associated with the establishment and maintenance of terraces and the resulting yields of maize and beans. Gross margin analysis was used to assess the economic benefits of constructing and maintaining the terrace ditch.

The gross margin was calculated using the following formula:

$GM = GI - VC$

Where, GM = Gross margin

GI = Gross Income

VC = Variable Costs

Gross income: This represents all the income for producing and marketing of maize and beans and is normally the total sales value for the crop. This included the average yields for each treatment and the gross benefits (based on the prevailing field prices of the crops) for all the four seasons for bean and the three seasons for maize harvests, in the short and long rain seasons of 2013-2015.

Variable costs: All the expenses incurred in the establishing, maintaining the terraces and in the production of the maize and beans.

3.5 Data analysis and management

The soil and plant data were first entered and processed in Microsoft Excel 2007 software then exported to GenStat for *Windows* 15th edition for analysis of variance (GenStat, 2013). Significant difference between and within treatments was separated at $P \leq 0.05$ using Duncan’s LSD.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1 The effect of terracing on soil moisture variability

4.1.1 Soil moisture variability at germination

Soil moisture content was found to exhibit a high degree of spatial and temporal variability. The lower slope position had significantly ($p \leq 0.05$) higher soil moisture % content at a depth of 30 cm than the other slope positions irrespective of cropping patterns and seasons (Fig. 4.1). Season II had the highest soil moisture while season III had the least (10%) soil moisture content. Cropping parttern three (CP3) had the greatest (18%) soil moisture content followed by cropping patterns two (CP2) and CP1. At this depth (30 cm) and plant growth stage, cropping patterns had no significant influence on soil moisture distribution. The slope position may have been the main determining factor on soil moisture distribution at this growth stage. This is in agreement with Liu, *et al*., (2011) who observed that field monitoring of the land type, direction of slope and land use type can influence the soil moisture conservation. This was based on a 3 year continuous investigation in He Zhuangping Village of Zhuanglang County in China. Land use type (terracing or not) plays an important role in water conservation, causing the major differences in crop growth that are most markedly shown in the root growth. In sloping land, crop roots are superficial, and absorb only shallow water at depths less than 40 cm. Specifically, the lower and lower middle slope positions appear to have similar moisture contents, while the upper and middle slope positions have lower soil moisture. This again suggests down slope movement of water.

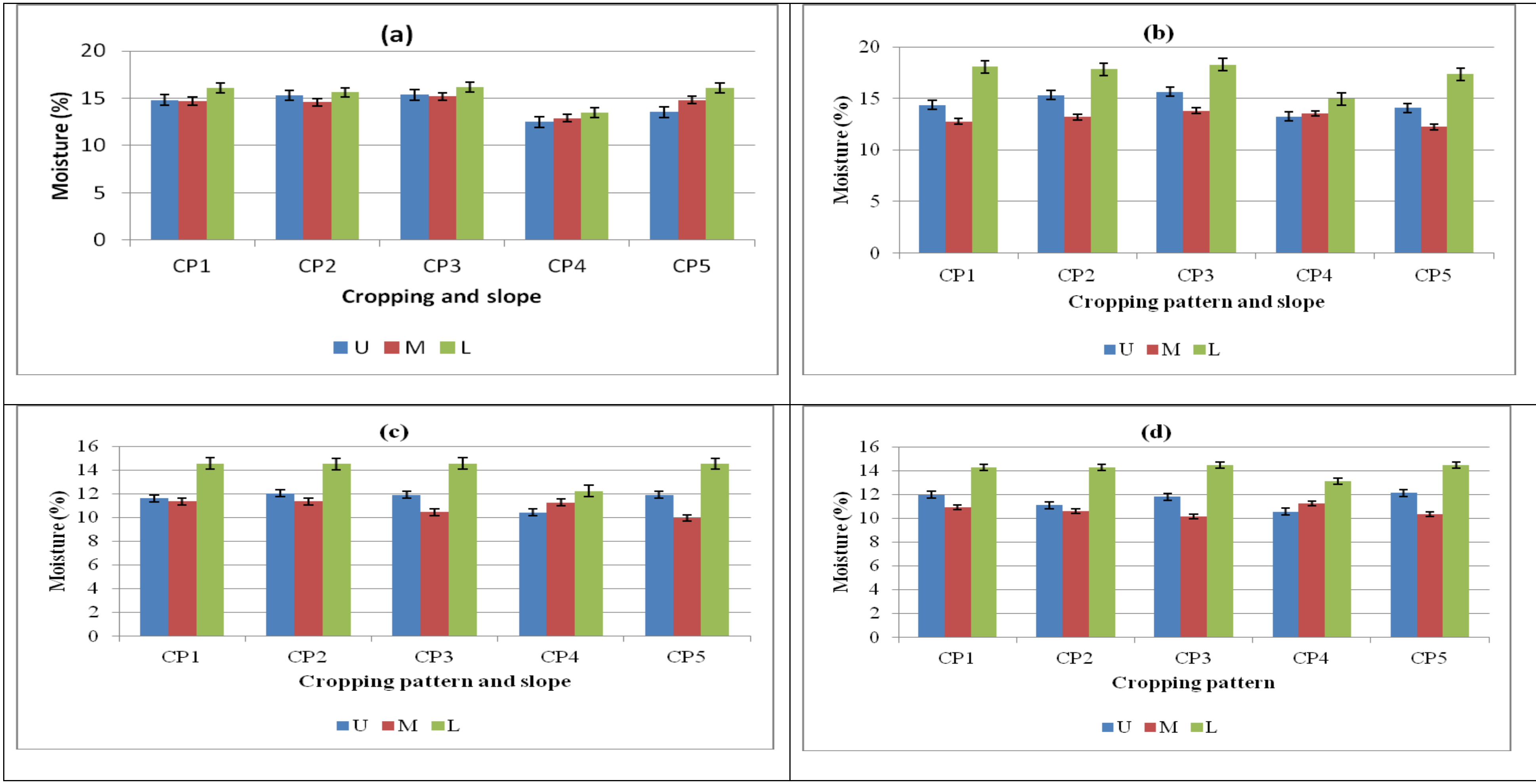

Figure 4.1: Soil moisture at germination at 30 cm depth in first season (a), second season (b), third season(c) and fourth season(d).
Terrace position =U-Upper, M-Middle, L-Lower ($LSD_{0.05}$)
Treatments = CP1: Maize and Bean intercrop in the upper and lower zones and sole maize in the middle
CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle
CP3: Sole maize crop in all the three slope positions
CP4: Maize and beans intercrop in all the three slope positions (farmers' practice)
CP5: Intercrop of maize and beans in upper, middle and lower slope position

4.1.2 Soil moisture at 9th leaf stage

The upper slope position had 6% less moisture than the lower position at 30 cm depth in season one. Cropping pattern three had the highest soil moisture (18%) while pattern four had the least moisture content (12.35%) at 30 cm depth in season one.

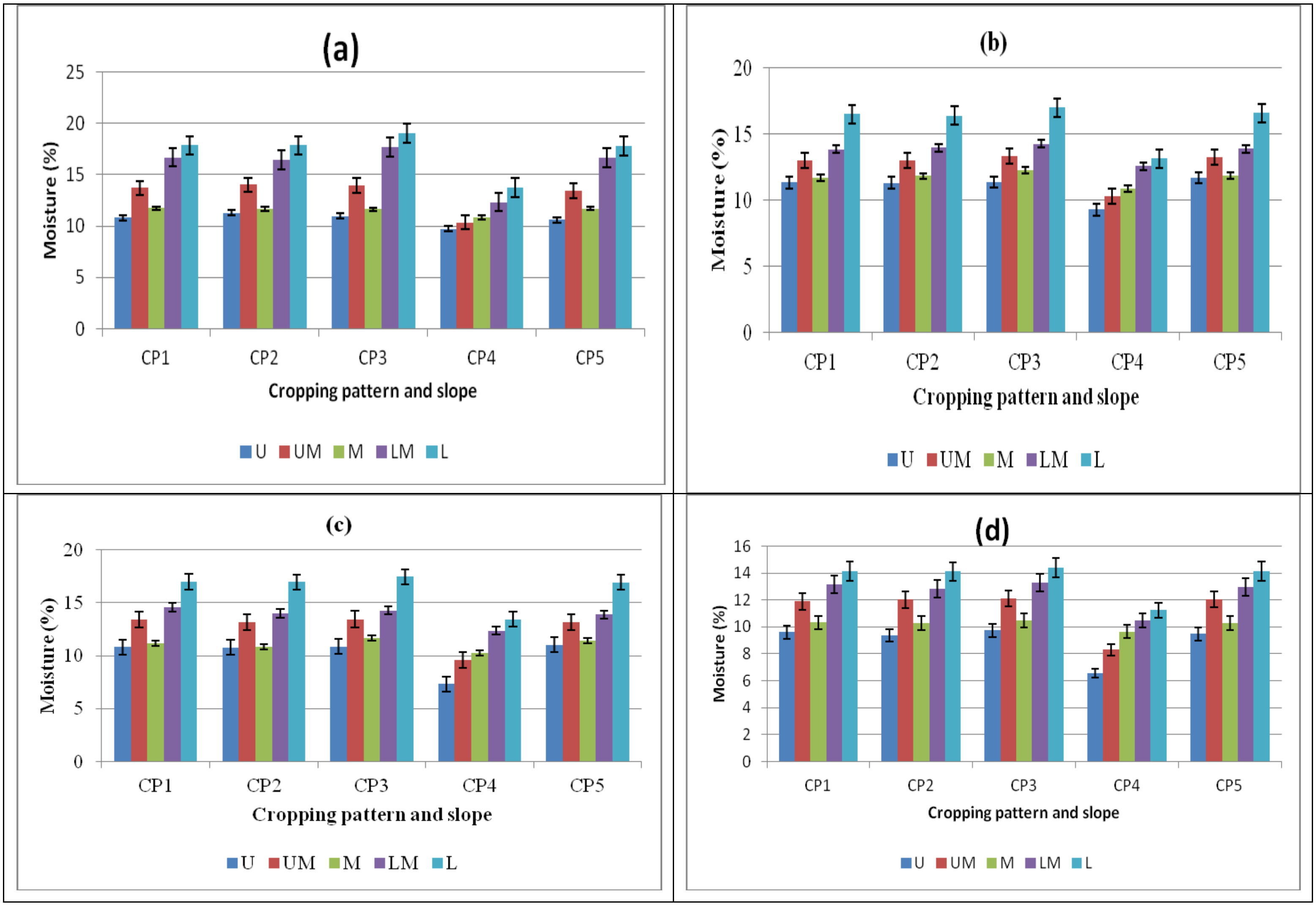

Figure 4.2 Soil moisture at 9th leaf stage at 30cm in season 1 (a), season II (b), season III(c) and season IV(d).

U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower ($LSD_{0.05}$)
Treatments: CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle
CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle
CP3: Sole maize crop in all the three slope positions
CP4: Maize and beans intercrop in all the three slope positions (farmers' practice)
CP5: Intercrop of maize and beans in upper, middle and lower slope positions

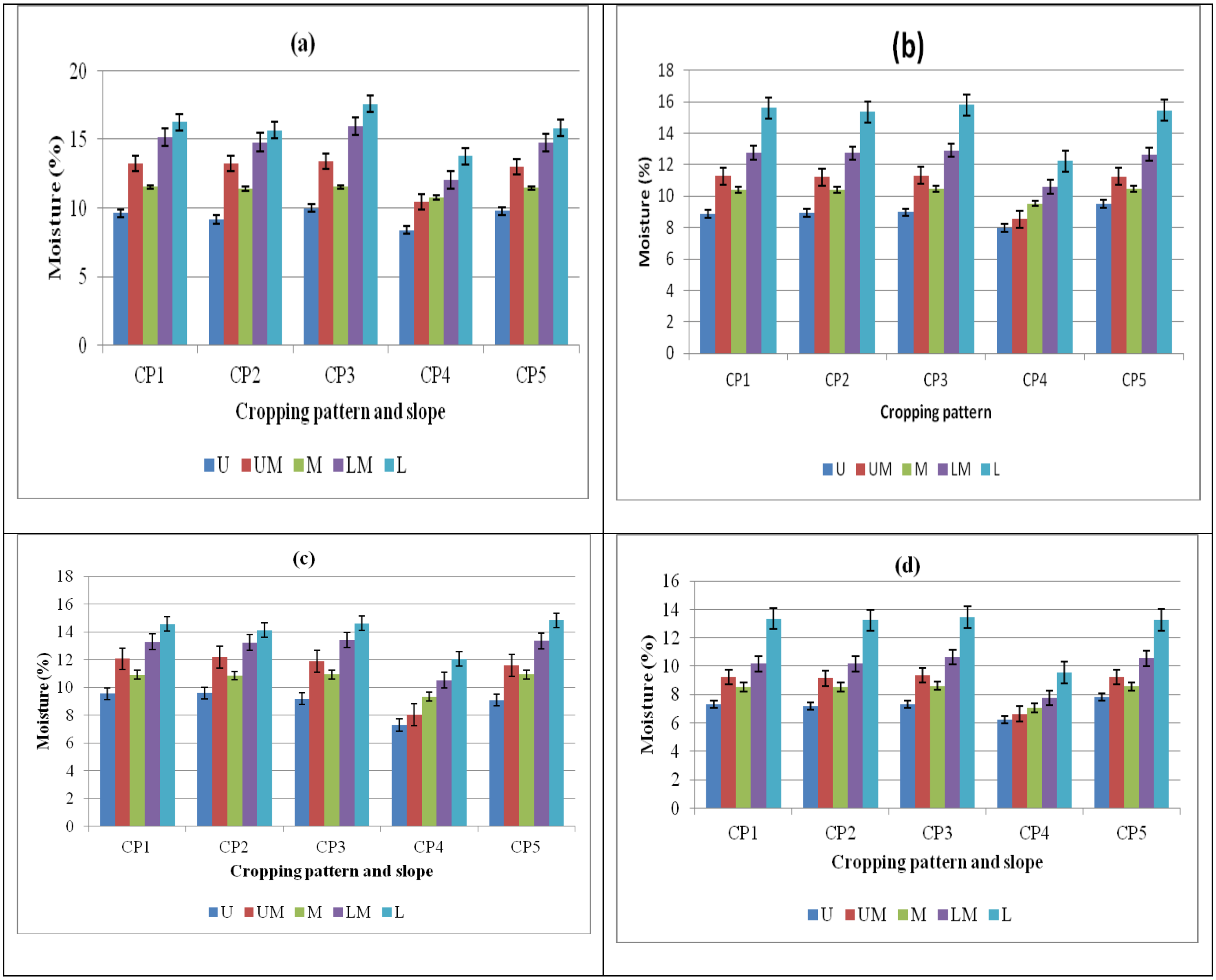

Figure 4.3: Soil moisture at 9th leaf stage at 50cm in season I(a), season II (b), season III(c) and season IV(d).

Key:

U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower ($LSD_{0.05}$)

Treatments: CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle

CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle

CP3: Sole maize crop in all the three slope positions

CP4: Maize and beans intercrop in all the three slope positions (farmers' practice)

CP5: Intercrop of maize and beans in upper, middle and lower zone.

On average, cropping pattern four had the lowest (9.54%) moisture content across all the seasons at both depths. The lower slope position had significantly ($p \leq 0.05$) higher soil moisture content % at a depth of 30cm and 50cm than the other slope positions across cropping patterns and seasons. The lower slope position had significantly ($p \leq 0.05$) higher soil moisture % content, for example at the depth of 50cm the reading were 15.1 and 17.5% at 75cm compared to the upper slope position which had on average 9.3 and 11% across cropping patterns and seasons (Fig. 4.4 and 4.5). Similarly, the slope position, cropping patterns and depth significantly ($p \leq 0.05$) influenced soil moisture content across all seasons (Fig. 4.3; 4.4; 4.5). Season two had the highest moisture 18.7% for cropping pattern three, while season IV recorded the least of 7.3% for cropping pattern four. The upper middle slope position had higher moisture readings than both the middle and upper positions respectively, this behaviour could have been attributed to lateral seepage from the terrace ditch, because the soils (andosols) at the trial site (Suswa) were found to form surface crusting within the first 5 to 10 cm. The high silt /clay ratio, low organic matter and high bulk density probably could have made the soils more prone not only to erosion but also facilitated the lateral seepage hence the higher moisture at the upper middle position, the lower middle and lower slope positions. The same is echoed by Pimentel (2006), who asserts that soil structure influences the ease at which it is eroded as soils with low organic matter and weak structural development like the Andosols of Suswa have low infiltration and are subject to water erosion as soil particles are easily displaced. In season two, cropping patterns one and three had the highest (5.2%) and (6.2%) more soil moisture content respectively in lower slope position than in upper position at 75 cm depth. The lower depth (75 cm) had the highest moisture content than the upper depth (50 cm) across all the cropping patterns and seasons and the upper and middle position had the least. These findings could probably be due to the general water movement down slope due to gravity and also because of sediment deposition due to erosion the lower slope position tend to have deeper soils which store more water. On average in season four, the lower depth had >1% moisture than in the upper depth under cropping pattern five. Cropping pattern four had the least soil moisture content at both depths in all the four seasons, this observation may be due to absence of soil and water conservation structures hence loss of both soil and water through run-off.

Similarly, Afyuni *et al.*, (1993) predicted highest total soil moisture content at the lower position, but observed the lowest moisture content at this position, with soil moisture increasing upslope. This was due to the coarse soil texture at the lower position and finer soil textures upslope (Afyuni *et al.*, 1993).

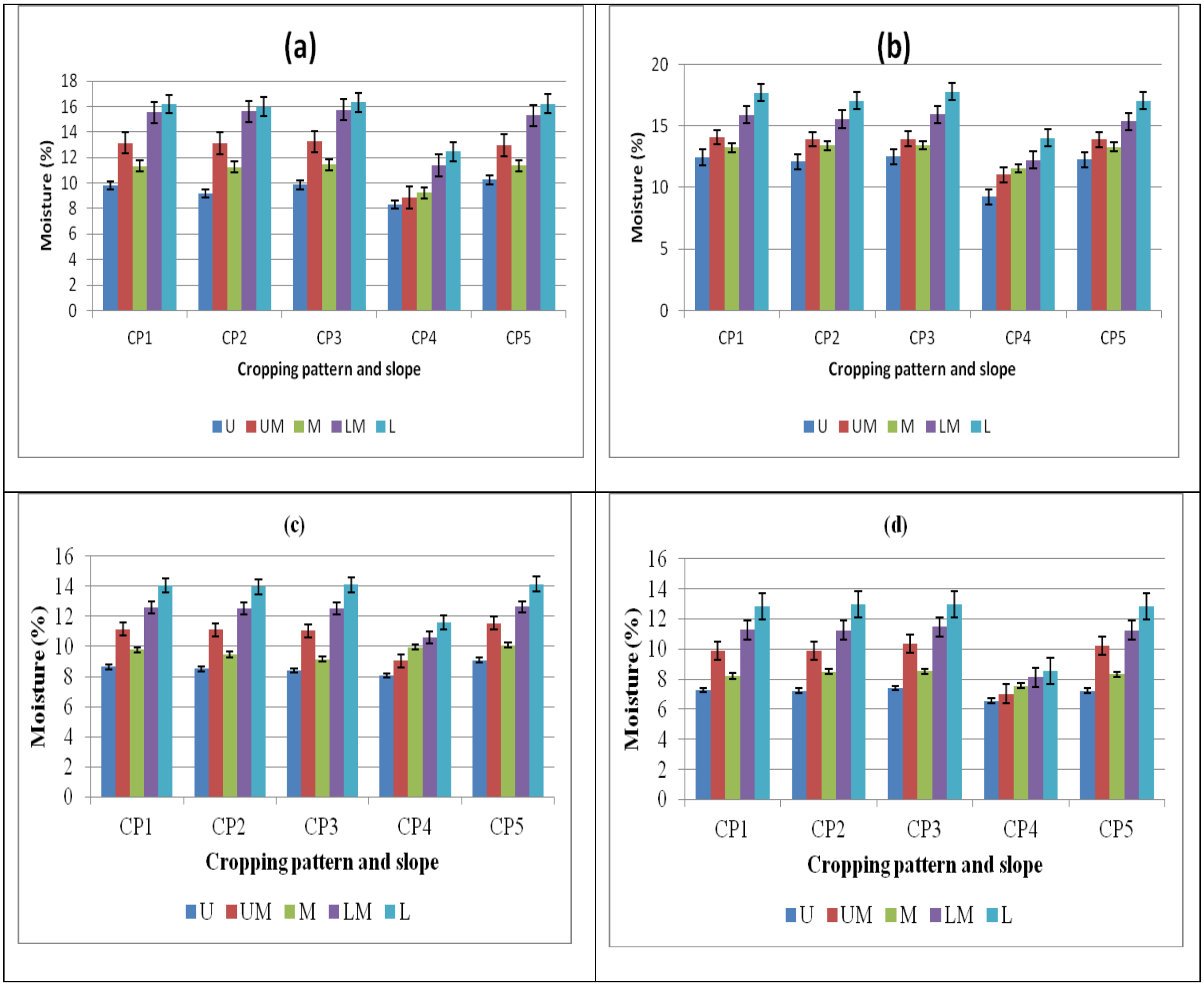

Figure 4.4: Soil moisture at tasseling at 50cm in season I (a) season II (b), season III(c) and season IV(d).

U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower ($LSD_{0.05}$)

Treatments:

CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle

CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle

CP3: Sole maize crop in all the three slope position

CP4: Maize and beans intercrop in all the three slope positions (farmers' practices)

CP5: Intercrop of maize and beans in upper, middle and lower slope positions

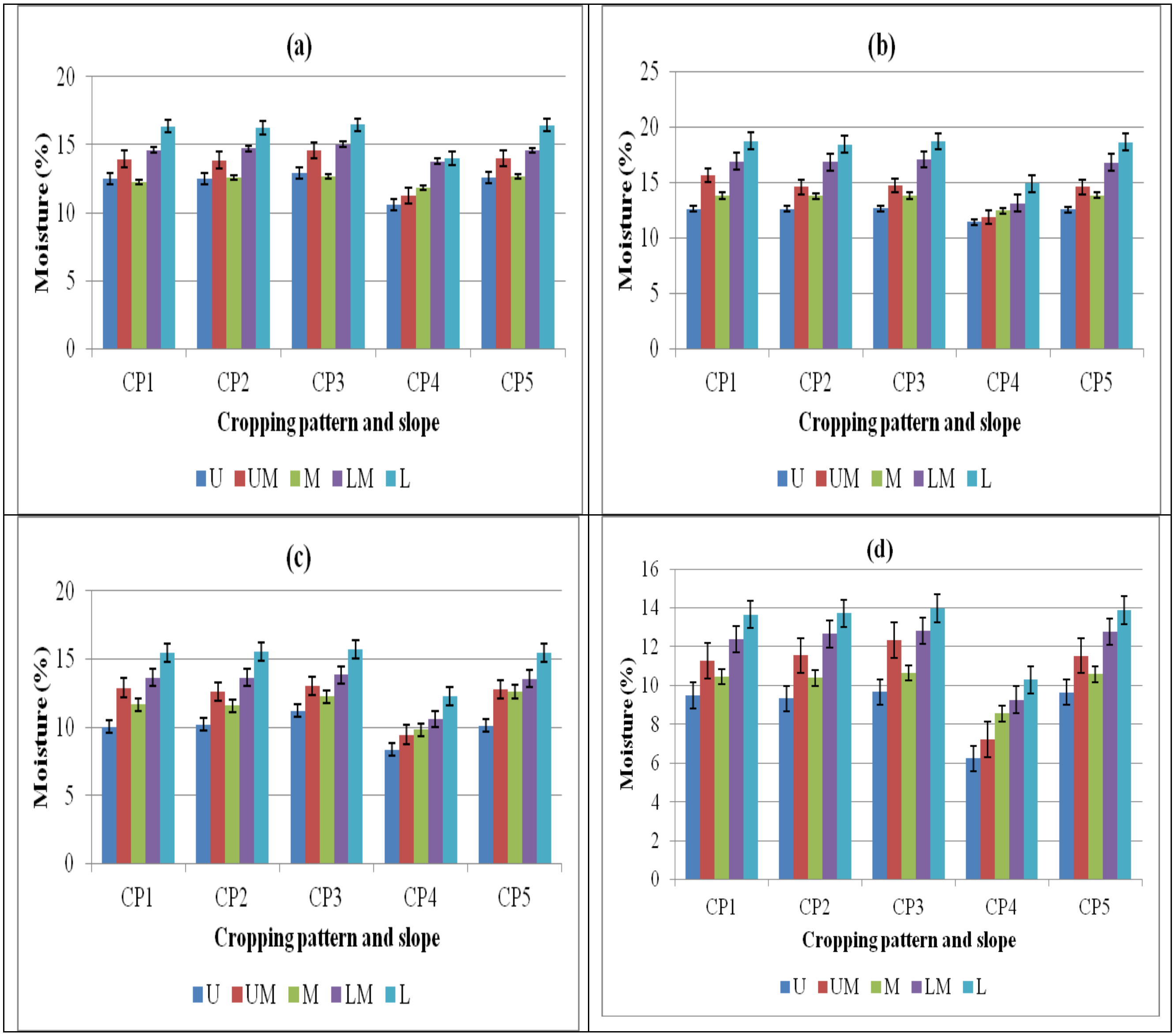

Figure 4.5: Soil moisture at tasseling at 75cm in season I(a), season II(b), season III (c) and season IV(d).

Key:
U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower (LSD$_{0.05}$)
Treatments: CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle
CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle
CP3: Sole maize crop in all the three slope position
CP4: Maize and beans intercrop in all the three slope positions (farmers' practice)
CP5: Intercrop of maize and beans in upper, middle and lower slope position

These moisture variations observed could be explained by the fact that water would naturally move and carry sediments down slope due to forces of gravity, resulting in deeper soils at this slope position which store more water while the upper and middle slope positions have shallower soils and therefore less water storage. When the water is taken up by plants from these deep soil section and from a shallow soil section, results in a faster depletion of soil moisture in the shallower soil section. This in turn resulted in a relation between soil moisture and soil depth after leaf out. This observation was more pronounced during periods of moisture stress in season IV. The higher soil moisture content at the upper middle terrace position may have been occasioned by lateral seepage from the terrace ditch while the lowest moisture content recorded in the upper slope position next to the ditch in all seasons was most likely occasioned by the dropped water level below the root zone created by the ditch, hence less available water for the crop, in addition the Suswa andosols have very little clay content that would have absorbed and help hold water collected in the terrace ditch.

Previous studies comparing water use among crops show varying impacts on soil moisture depletion at varying depths (Schwinning and Sala, 2004). In most cases soil-water extraction by crop roots is not uniformly distributed in the soil profile and varies spatially and temporarily, under non stressed water and nutrient conditions and if root development is not impended by restrictive soil layer or other factors. Soil water extraction follows a conical water uptake patter of 40, 30 and 20 and 10 % of total water uptake from the first, second, third and last one fourth of plant rooting depth Schwinning *et al.,* 2004). Trends and magnitude of soil-water extraction depend on crop type and phonological development as well as external factors imposed on the crop physiological functions including among others time of planting and population density, soil physical and chemical properties and micro climatic conditions especially seasonal precipitation distribution and amount (Irmak and Rudnick, 2014). These external forces can alter the typical conical water uptake pattern. The extraction trends of maize plant, illustrate that early in the growing season the majority of the soil-water extraction occurred in the 30 cm and throughout the growth period more than 90% of the total water extraction occurred in the top 90 cm. Soy bean extracts more water from a depth below 80 cm as growth progresses, regardless of water availability at the surface. A drought-resistant soybean cultivar was shown to deplete more soil moisture from the soil horizon above 68 cm compared to a non-drought variety, as a result of the greater lateral spread and fibrosity of its roots (Anwar, 2014). In this study variability in soil moisture content down the profile may have been an indicator of natural movement of water as influenced by gravity as well as the conical nature of soil water depletion by pants like maize, hence moving from the region of higher potential to a lower potential area.

In an experiment carried out in Biyongo in Indonesia, Husain *et al.,* (2013) reported that terraces increased the average soil moisture content in 90 cm soil depth by more than 50% than that of non terraced land. Within the terraced, field compartmental bunding increased soil moisture by 18.2% higher than that of plain bed (control). This indicated that in-situ moisture conservation measures are effective to increase soil moisture compared to plain bed. It was also observed that mean soil moisture fluctuation in the soil profile is moderately more at 60 cm depth compared to 30 cm irrespective of type of conservation techniques. In this study the terrace embankment seemed to have played a major role in trapping soil moisture down the slope.

Soil moisture at vertical direction was influenced by soil factors such as texture, bulk density as well as environmental factors such as rainfall, evaporation and land use type (Wang, *et al*., 2006). Reports by Qiu *et al*., (2001); Plessis, (2003) also indicate that slope and season influence the spatial variability of soil moisture and during the growing period, crops in terraces can absorb more water than in sloping land, thus increasing the uptake of deep moisture and reducing evaporation losses.

4.2 Results of selected soil nutrient distribution at the beginning and at the end of trials

There were significant ($p \leq 0.05$) difference in soil nutrient distribution as affected by slope and season

4.2.1 Soil pH

Soil pH did not show significant variations down the slope at the beginning of the trials (August, 2013) and at the end (May, 2015). The mean value of pH in water for the slope positions in the beginning and of the trial period was 6.1. One of the probable explanations for this is that because the trial site (Suswa) is generally dry and in dry climates, soil weathering and leaching are less intense, therefore the pH remained neutral or alkaline overtime. In addition this area does not have much agricultural activities like growing of crops which could have had an influence on the soil pH due to use of fertilizer or lime. This is in agreement with the findings of Asadi *et al*., (2010) who found a non-significant difference in soil pH between soils on conserved dry farm land and degraded rangeland of semiarid region of Iran, the same is echoed by Khan *et al.*, (2013) who reported that soil pH did not show significant variation down the slope in a study on the effect of slope position on soil physico-chemical properties in Samarbagh, Pakistan.

The findings by Khan, *et al*., (2013) were contrary to those of Moges and Holden (2008) and Aweto and Enaruvbe (2010) who found a significant difference in pH by slope position at both 0 to 15 cm and 15 to 30 cm soil depths. The reason for the decline in pH from upper to lower position was partly due to the decline in exchangeable cations (especially magnesium) and base saturation down slope. Moges and Holden (2008) and Aweto and Enaruvbe (2010), reported that for every half-unit drop in soil pH, percent base saturation declined by about 15%. The higher pH value from lower slope position could be due to high CEC and exchangeable bases, probably eroded and deposited in the lower slope positions. The upper slope part is characterized by higher erosion and lower depositions while the lower part is usually the zone of deposition.

4.2.2 Soil organic carbon

Soil carbon was significantly ($p \leq 0.05$) affected by different slope positions in 2015 (Table 4.1). The lower slope position had the highest soil carbon content followed by mid and upper slope position. The lower slope position had 16 and 21% higher soil carbon than the mid and upper slope positions, respectively. This probably may be due to the presence of sediment deposited at the lower slope position. Because soil carbon is highly concentrated at the top layers of soils; it is highly affected by erosion and in addition higher soil carbon content may have been due to lower erosion rate and higher (7.5 t ha^{-1}) biomass production on average at this position compared to the upper slope positions (3.5 tha^{-1}).

Table: 4.1 Soil nutrient chemical analysis at beginning and end of trials.

Slope	August, 2013					May, 2015				
	pH (H_2O)	C (%)	N (%)	P (ppm)	K (Cmol/kg)	pH (H_2O)	C (%)	N (%)	P (ppm)	K (Cmol/kg)
U	6.06	1.31	0.16	12.41	3.06	6.16	1.81	0.12	17.29	1.90
M	6.06	1.30	0.16	13.56	3.11	6.04	2.03	0.21	23.15	2.23
L	6.06	1.34	0.19	18.73	3.11	6.15	2.62	0.35	31.03	2.67
Means	6.06	1.32	0.17	14.9	3.09	6.12	2.15	0.23	23.82	2.26
LSD$_{(0.05}$	0.25	0.48	0.06	6.89	0.52					
CV (%)	2.5	16.8	19.8	21.8	11.9					
SE	0.13	0.24	0.03	3.44	0.26					

Key: U-Upper, M-Middle, L-Lower

Soil carbon is primarily composed of biomass and non-biomass sources biomass carbon includes various bacteria and fungi. Non-biomass carbon sources or substrates reflect the chemical composition of plant biomass, and primarily include cellulose, starch, lignin, and other diverse organic carbon compounds.The results of this study were in agreement with those of Bot and Benites (2005), Alemayehu (2007), Moges and Holden (2008), Aweto and Enaruvbe (2010) and Malgwi and Abu (2011), who argued that soils in lower topographic locations are not only characterized by lower slope angles but also held greater quantity of water than higher slope soil that slows down the rate of microbial degradation and mineralization of organic matter in toe and crest slope positions (Lopez *et al*., 2003 and Gao *et al*., 2009). Mulugeta and Stahr (2010) also found higher soil organic matter (3.69%) for conserved catchment as compared to non- conserved one (2.24%). Soil organic carbon contents between accumulation and loss zones were highly significantly different ($p \leq 0.01$), according to Million (2003) the variations in mean value of organic carbon could be attributed to the erosion reduction effects of soil and water conservation measures implemented and biomass accumulation. The findings of Million (2003) revealed that soil organic carbon content of three terraced sites with original slopes of 15, 25 and 35% were higher compared with the corresponding non-terraced sites of similar slopes. An observation, which may have been occasioned by the washing away of carbon from the upper part of terraces and settling down at the lower parts.

4.2.3 Soil nitrogen

The results show that the investigated positions, upper, mid slope and lower slope had different soil nitrogen status. Soil N was significantly ($p \leq 0.05$) affected by different slope positions in 2015 (Table 4.1). The bottom slope position had the highest soil N content than both the mid and top slope position. The bottom slope position had 33 and 48% higher N than the mid and top-slope positions, respectively. This observation was attributed to the transportation of nitrogen from the upper slope position, through run off erosion, hence contributing to higher soil nitrogen levels at the slope base compared to the middle and upper slope positions. The slightly higher levels of total nitrogen at the end of the trial period may be attributed to the residual effect of fertilizer application during planting and top dressing in all the four.

Similar findings were echoed by Alemayehu (2007) and Ofori *et al.,* (2013), who reported that the difference between the deposition (lower slope) and loss zones (upper) for total N was statistically significant ($p \leq 0.05$). They also found higher total N levels on lower parts of the terrace compared to the upper parts of terraces. Siriri *et al*., (2005) also reported lower total N values on the upper parts of terraces and moderately increased on the lower parts. Mllion (2003) found out that the total nitrogen content of the terraced site with the slope of 15, 25 and 35% were higher by 26, 34 and 14%, respectively compared to their corresponding non-terraced sloping areas. Lower slope had the highest total nitrogen than all other positions followed by crest. Statistically, the difference between toe and crest was insignificant while toe slope significantly varied from back slope, shoulder slope and foot slope (Million, 2003). Wolde and Veldkamp (2005) also showed that upper slope positions had lower total nitrogen than that of middle and foot slopes in the terraced fields.

4.2.4 Available Phosphorus

Results showed that slope position and season had significant ($p \leq 0.05$) effects on phosphorus (P) and the bottom slope had the highest soil P (31.03 ppm) followed by mid slope (23.15 ppm) and top slope (17.29 ppm) positions, respectively (Table: 4.1). The increase in P at bottom slope was 25 and 44% higher than the mid and top slopes positions, respectively at the end of the trials. The variation in available P at the beginning and at the end of the trials as well as between deposition and loss zones could be attributed to washing out in the upper parts and accumulation at the lower parts leading to elevated amount of moisture resulting in high biomass production and hence higher soil organic matter. Soil organic matter boosts soil microbial activity, which enhances the microbiologically-driven processes in soil phosphorus dynamics. The microbial phosphorus pool is increased when greater amounts of organic matter are made available. The slightly higher levels of total available P at the end of the trial period like N may be attributed to the residual effect of fertilizer application during the trials period.

Similar results were also reported by Tadele *et al.*, (2011) who indicated that with higher P concentration in the depositions zone there should be relatively higher biomass production and which in turn produces higher soil organic matter which is the store of Phosphorus. These findings were in agreement with those of Moges and Holden (2008) as well as Wolde and Veldkamp (2005) who found higher mean value of P from lower slope position compared to middle slope and upper slope positions. The higher P content in lower slope positions could be associated with higher soil organic matter at the lower slope position.

4.2.5 Available potassium

Potassium (K) was found not to be significantly different at the investigated slope positions, at the beginning as well as at the end of the trial period (Table: 4.1). However, the bottom slope position had the higher K readings comparatively. K content at the end of the trials (May, 2015) was on average 16 and 29% higher in the bottom than in the mid and top slope positions, respectively. This observation could be attributed elevated moisture availability at the lower slope position giving rise to improved levels of soil available potassium (water soluble potassium) plus that held on the exchange sites on clay particles (exchangeable K). The baseline (August, 2013) results for K showed no significant difference in all slope positions compared to the end of the experiment period. For example the upper, middle and lower slope positions had 3.06, 3.11 and 3.11Cmol/kg respectively at the beginning of the trials compared to 1.90, 2.23 and 2.67Cmols/Kg respectively at the end of the trials (Table 4.1). The lower values at the end of the trials probably could be associated with lower rainfall (92.4mm) received compared to 450mm at the beginning of the trials. This indicates that potassium may have been influenced by low moisture resulting in less recycling to the soil and less replenishment of the soluble or easily exchangeable soil K pools. It is therefore suspected that as the solution of the soil decreased with the low soil moisture, the potassium ions may have been bound into the soil layers resulting in lower potassium readings as soil analysis do not report on the bound potassium ions. The results of this study are in agreement with Tadele *et al*., (2011) who found a non significant difference in exchangeable bases among different soil and water conservation measures. Zougmore *et al*., (2002) also found a non-significant difference in mean value for exchangeable Ca^{2+} after five years of soil conservation by bund in Burkina Faso. Aweto and Enaruvbe (2010) found highest values of exchangeable K and Na on upper slopes while Moges and Holden (2008) found non-significance difference of exchangeable Na^{+} along a toposequence. Exchangeable K^{+}, Ca^{2+}, and Mg^{2+} were significantly higher on toe slope than other slope positions, which could be as the result of lower erosion and higher deposition. Similarly in a field experiment in Murang'a county Kenya, Ovuka (2000) found out that there was a higher concentration of nutrients in the lower part of the slope an indication of erosion of top fertile soils up-slope. The report indicated that Nitrogen, Phosphorus and Carbon were the most affected nutrients regarding slope position. Nitrogen was found at high levels at the slope base and too low in upper slope position to support meaningful agricultural production. Compared with a 15% slope the soil organic content of the terraced land increased by 26%, total N by 8%, total P by 4%, fast acting N by 12%, and fast acting P by 20% (Liu, *et al*., 2011). The tests showed that terracing created better conditions for water and nutrient conservation than the sloping land, especially in the 40–180 cm depths, was available to the crop for effective use during the dry season (Liu *et al*., 2011). Like wise the results of this study showed that differences in plant responses to landscape position exist primarily because of changes in soils and their associated properties, meaning landscape position can be helpful in identifying zones of moisture and nutrient accumulation which can aid in fertilizer management decisions. The other probable explanation for the lower potassium levels at the end of the trials was due to harvest, since soils can become depleted in potassium when crops are harvested through removal of whole plant from the field, this is agreement with Lei *et al., (*2000), who reported that a maize crop removed as grain only about 18 kgs of potassium but, if harvested for corn silage, the same crop removes 68 kgs of potassium since most K is concentrated in the stalk and leaves. Lei *et al*., (2000) therefore recommends returning crop residue to the maize field in order to maintain soil K fertility.

4.3 The effect of terracing on N, P and K uptake in maize above ground biomass and grain

4.3.1 Nitrogen uptake in maize above ground biomass

There was a significant difference ($p \leq 0.05$) in N uptake in all slope positions (Table 4.2). The lower slope position had the highest N uptake followed by the lower middle and upper middle slope positions respectively.

Table: 4.2 Effect of slope position and cropping patterns on N (%) uptake in maize above ground biomass

Slope	Season II						Season IV						
	CP1	CP2	CP3	CP4	CP5	Mean	CP1	CP2	CP3	CP4	CP5	Mean	
U	0.71	0.76	0.78	0.62	0.77	0.73	0.61	0.60	0.67	0.45	0.72	0.61	0.67
UM	1.01	1.16	1.38	0.84	1.24	1.13	0.78	0.91	1.01	0.71	1.01	0.88	1.01
M	0.77	*	0.96	0.90	0.92	0.84	0.69	*	0.95	0.75	0.93	0.83	0.84
LM	1.59	1.63	1.66	1.05	1.67	1.52	1.22	1.25	1.46	0.99	1.44	1.27	1.40
L	2.04	2.07	2.09	1.19	2.08	1.89	1.59	1.81	1.97	1.23	1.85	1.69	1.79
Means	1.22	1.41	1.37	0.93	1.36		0.98	1.14	1.21	0.83	1.19		

*=Bean plot
CV(%) = 14.1, LSD$_{(0.05)}$= 0.26, SE(TREATMENTS)=0.04, SE(SEASONS*CROPPING PATTERNS*SLOPE POSITION*DEPTH)=0.13
U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower, LSD value is for means comparison along the columns
Treatments:
CP1: Maize and Bean intercrop in the upper and lower zones and sole maize in the middle
CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle
CP3: Sole maize crop in all the three zones
CP4: Maize and beans in all the three slope positions (farmers' practice)
CP5: Intercrop of maize and beans in upper, middle and lower zone.

The lowest N uptake (0.67%) values were recorded for the upper and middle slope positions, this observation probably can be because in the upper slope position the presence of the ditch dropped the water level making it less available, hence equally less available nitrogen. Likewise the low (0.84%) levels of N in the middle slope position were also attributed to the less amount of water at this position due to loss through runoff. The Nitrogen uptake in upper middle slope position was higher than in the middle slope position and upper slope in both seasons. The pattern created by N uptake could be attributed to the availability of moisture at the upper middle position occasioned by lateral seepage of water from the terrace ditch and moisture and nutrient accumulation due to runoff and sediment deposition in the lower middle and lower position. Adequate moisture in these slope positions may have influenced soil available nitrogen resulting in improved uptake of nitrogen by diffusion and root interaction, and increased organic matter decomposition which released the nitrogen. There was also significant difference in N uptake in maize biomass according to cropping patterns. Cropping pattern four (control) however recorded on average the lowest (0.93 in season II and 0.83 in season IV) uptake in both seasons. This observation could be linked to the absence of lateral seepage and zones of moisture and nutrient accumulation in this treatment. The N uptake was significantly higher (1.21 %) in cropping pattern three than in pattern four (0.83 %) in season four. The amount of rainfall received in season II (416mm) compared to (92.4 mm) in season IV may be linked to the generally lower N uptake in season IV.

Agricultural soils in semiarid environments are commonly deficient in N (Abrol and Raghuram (2007). In this runoff agricultural system, however, storm flow transport organic matter, sediments, and nutrients to fields located in the lower slope positions. As water flows over the landscape, nutrients are dissolved and transported. Analyses of runoff water collected at the controlled experiment fields indicate that these waters deliver N and other nutrients from the watershed to the lower fields (Norton, 2000). In addition, precipitation itself contributes plant usable forms of N (nitrate-nitrogen and ammonium) to the system. Organic matter averaged 2.3% (± 0.5) by mass and typically; soils developed in semiarid zones are low in organic matter, near 0 to about 3 or 4% (Muenchrath *et al*., 2000). Organic matter contributes to soil water-holding capacity and nutrient availability for crop production. Likewise the results from this study showed that there was low N in the upper slope position compared to the lower slope position hence the higher N uptake. In addition the lower rainfall received in season IV compared to season two contributed to the lower N uptake, which was also attributed to low nutrient availability. Nutrients are hypothesized to accumulate down slope in conjunction with water movement and organic matter deposition (Brady and Weil 2002).

4.3.2 Phosphorus uptake in maize above ground biomass

The results presented in Table 4.3, show that P uptake was statistically significant ($p \leq 0.05$) between all the slope positions and cropping patterns in both seasons. On average the middle slope position had the least P uptake (1125 ppm) compared to the upper slope position (1340 ppm) and upper middle Position (1430 ppm). The lower slope position (1703 ppm) and the lower middle position (1579 ppm) recorded the highest uptake respectively, an observation that could be linked to the presence of moisture in the upper middle slope position occasioned by lateral seepage from the terrace ditch and sediment and moisture availability at lower slope positions occasioned by erosion by wind and runoff upslope. Because soil organic matter is mainly concentrated on the top layers of soils; it is greatly affected by erosion. Organic forms of P are found in humus and other organic material. Phosphorus in organic materials is released by a mineralization process involving soil organisms. The activity of these microbes is highly influenced by soil moisture and temperature and therefore probably the higher P at the lower middle and lower slope position. In addition, soils in lower topographic locations are not only characterized by lower slope angles but also hold greater quantity of water that slows down the rate of microbial degradation and mineralization of organic matter in low slope positions. Higher P content and uptake in lower slope positions could be associated with higher Nitrogen, as phosphorus absorption and use efficiency by crops is improved by the presence of ammonium-nitrogen (NH4-N) in the soil with the P. Cropping pattern four (control) had the least (1368 ppm in season four and 1373 ppm in season two) P uptake while pattern five and three had the highest (1485 ppm and 1445 ppm) in both seasons in season II and IV respectively. This observation could be linked to loss of Phosphorus, since P movement in landscapes is associated with soil erosion because P is adsorbed on solid soil component. The control plots lacked terrace embankment that would have prevented this loss.

Table: 4.3 Effect of season, slope position and cropping patterns on P (ppm) uptake in maize above ground biomass

Slope	Season II						Season IV						Means
	CP1	CP2	CP3	CP4	CP5	Mean	CP1	CP2	CP3	CP4	CP5	Mean	
U	1375	1376	1348	1315	1355	1354	1325	1341	1321	1312	1335	1327	1340
UM	1485	1492	1427	1392	1428	1445	1431	1444	1398	1389	1418	1416	1430
M	1126	*	1141	1131	1151	1137	1112	*	1118	1100	1133	1116	1126
LM	1555	1582	1678	1456	1703	1595	1505	1588	1644	1446	1631	1563	1579
L	1758	1705	1778	1568	1791	1720	1666	1732	1742	1594	1694	1686	1703
Means	1460	1539	1474	1373	1485		1408	1444	1445	1368	1442		

*=Bean plot

CV(%) = 2.9, LSD$_{(0.05)}$= 67.9, SE(TREATMENTS)=10.8, SE(SEASONS*CROPPING PATTERNS*SLOPE POSITION*DEPTH)=34.2
U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower, LSD value is for means comparison along the columns
Treatments:
CP1: Maize and Bean intercrop in the upper and lower zones and sole maize in the middle
CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle
CP3: Sole maize crop in all the three zones
CP4: Maize and beans in all the three slope positions (farmers' practice)
CP5: Intercrop of maize and beans in upper, middle and lower zone.

Cropping pattern four lacked both the terrace ditch and embankment that could have allowed for lateral seepage as well as sediment and moisture accumulation. On the effect of seasonality, season two had in general higher P uptake across slope and cropping pattern that may be attributed to the higher rainfall received in season two (416.1 mm) compared to season four (92.4 mm).

4.3.3 Potassium uptake in maize above ground biomass

There were significant differences ($p \leq 0.05$) in K uptake in maize biomass in all the slope positions and cropping patterns in both seasons (Table 4.4). Cropping pattern five had the highest K uptake (2628 ppm) in season four while pattern four had the least (2392 ppm) in season two.

Table: 4.4 Effect of season, slope position and cropping patterns on K (ppm) uptake in maize above ground biomass

Slope	Season II						Season IV						Means
	CP1	CP2	CP3	CP4	CP5	Mean	CP1	CP2	CP3	CP4	CP5	Mean	
U	1958	1875	1958	1917	1958	1933	1949	1866	1949	1907	1949	1924	1928
UM	2417	2125	2250	2208	2333	2267	2197	2239	2405	2114	2322	2255	2255
M	2125	*	1917	2125	2083	2062	2031	*	2197	1907	2111	2062	2062
LM	3208	2917	2833	2667	3083	2942	2778	2861	3068	2819	3109	2927	2927
L	3667	3375	3667	3042	3625	3475	3317	3358	3648	3317	3648	3458	3467
Means	2675	2571	2525	2392	2616		2454	2581	2653	2413	2628		

*=Bean plot

CV(%) = 12.9, $LSD_{(0.05)}$= 530.4, SE(TREATMENTS)=84.5, SE(SEASONS*CROPPING PATTERNS*SLOPE POSITION*DEPTH)=267.1
U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower, LSD value is for means comparison along the columns
Treatments:
CP1: Maize and Bean intercrop in the upper and lower zones and sole maize in the middle
CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle
CP3: Sole maize crop in all the three zones
CP4: Maize and beans in all the three slope positions (farmers' practice)
CP5: Intercrop of maize and beans in upper, middle and lower zone.

The lower slope positions had the highest K uptake while the upper positions had the least in both seasons. The upper middle slope position recorded higher K uptake compared to middle and upper slope positions respectively. The lower slope positions had 44% more K uptake than the upper positions in season four. The high K uptake in the upper middle slope position and in the lower middle and lower position is due to availability of moisture occasioned by lateral seepage from the terrace ditch. Moisture is needed for K to move to plant roots for uptake as well as for root growth through the soil to “new” supplies of K. It is needed for mass-flow movement of K to the plant roots with water and for the diffusion of K to the roots to resupply that taken up by the roots. The lower values in the upper and middle slope positions were therefore caused by low moisture which restricted nutrient uptake. For example at the 9th leaf stage of maize the soil moisture readings were 8.7% in the upper, compared to 15.7% in the lower slope position.

4.3.4 Nitrogen uptake in maize grain

The effect of slope positions and cropping patterns on N uptake in maize grain was observed in both seasons (Table 4.5). There was however no significant differences in N grain uptake in all the cropping patterns in all the investigated seasons. N uptake was generally higher in season one and two compared to season three across slope position and cropping pattern, an observation that is attributed to higher amount of rainfall in season one (450mm) and season two (416 mm) compared to season three (141mm). There were significant differences in N grain uptake in the slope positions in the three seasons, the lower slope on average position had 1.6% compared to upper position with 1.28%, on average. This was attributed to moisture accumulation at the terrace embankment both through natural and accelerated soil erosion, which contributed to higher soil N uptake at the lower slope position compared with other slope positions.

Table: 4.5 Effect of season, slope position and cropping patterns on maize grain N (%) uptake

Season	I						II						III						Mean of means
Slope	CP1	CP2	CP3	CP4	CP5	Mean	CP1	CP2	CP3	CP4	CP5	Mean	CP1	CP2	CP3	CP4	CP5	Mean	
U	1.30	1.34	1.31	1.33	1.38	1.33	1.28	1.32	1.35	1.30	1.36	1.32	1.17	1.17	1.22	1.17	1.19	1.18	1.28
UM	1.52	1.47	1.45	1.36	1.53	1.47	1.48	1.46	1.42	1.34	1.52	1.44	1.24	1.21	1.24	1.19	1.23	1.22	1.38
M	1.48	*	1.34	1.41	1.38	1.41	1.47	*	1.32	1.38	1.36	1.38	1.21	*	1.20	1.21	1.20	1.20	1.33
LM	1.60	1.60	1.68	1.51	1.65	1.61	1.57	1.59	1.69	1.48	1.64	1.59	1.28	1.26	1.31	1.22	1.26	1.27	1.49
L	1.72	1.76	1.86	1.59	1.77	1.74	1.72	1.76	1.86	1.56	1.78	1.74	1.35	1.33	1.38	1.25	1.34	1.33	1.6
Mean	1.52	1.54	1.53	1.44	1.54		1.51	1.53	1.53	1.41	1.53		1.25	1.24	1.27	1.21	1.24		

*=Bean plot

CV (%) = 4.1, LSD$_{(0.05)}$= 0.09, SE (TREATMENTS)=0.02, SE (SEASONS*CROPPING PATTERNS*SLOPE POSITION*DEPTH)=0.05
U-Upper, M-Middle, L-Lower, LSD value is for means comparison along the columns
Treatments: CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle
CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle
CP3: Sole maize crop in all the three zones
CP4: Maize and beans in all the three slope positions (farmers' practices)
CP5: Intercrop of maize and beans in upper, middle and lower zone.

The moisture availability at this slope position may have exerted considerable influence on the efficiency of water use and in the mobilization of nitrogen from other parts of the plant to the grain as the grain developed giving rise to high grain nitrogen accumulation. In addition data from this study also indicated that on average there was higher` (4564ppm) levels of potassium at lower slope position, compared to (3357ppm) in the upper slope. The interaction of N and K may have resulted in increased nitrogen uptake and use by the plant and hence more N accumulation in the grain.

4.3.5 Phosphorus uptake in maize grain

There was a pronounced effect of slope position on P grain uptake in maize in all seasons (Table 4.6). The lower slope position had the highest (3034 ppm) P grain uptake while the upper position had the least (1618 ppm) in season three. The higher P grain uptake at the lower slope position could be associated with the accumulation of moisture as soil moisture increases P availability and uptake. Results from this study have shown that there were higher levels of both nitrogen (1.6%) and potassium (4812ppm) which could have given rise to an interaction of these elements hence improved uptake.

Table: 4.6 Effect of season, slope position and cropping patterns on maize grain P (ppm) uptake

Season	I						II						III						Mean of means
Slope	CP1	CP2	CP3	CP4	CP5	Mean	CP1	CP2	CP3	CP4	CP5	Mean	CP1	CP2	CP3	CP4	CP5	Mean	
U	1701	1918	1759	1728	1751	1771	1693	1901	1684	1694	1729	1740	1701	1618	1801	1851	1626	1719	1743
UM	1976	1916	2003	1992	2228	2023	1966	1899	2054	1958	2176	2011	2184	1934	2284	1968	1901	2054	2029
M	1859	*	1818	1855	1926	1865	1809	*	1816	1838	1874	1834	1868	*	2001	2001	1851	1930	1876
LM	2339	2275	2083	2173	2378	2250	2323	2341	2264	2161	2363	2290	2363	2418	2534	2201	2501	2403	2314
L	2645	2451	2811	2497	2638	2608	2638	2561	2801	2494	2624	2624	2746	2834	3034	2384	2834	2766	2666
Mean	2104	2140	2095	2049	2184		2086	2176	2124	2029	2153		2172	2201	2331	2081	2143		

*=Bean plot

CV(%) = 8.4, LSD$_{(0.05)}$= 279, SE(TREATMENTS)=100, SE(SEASONS*CROPPING PATTERNS*SLOPE POSITION*DEPTH)=141
U-Upper, M-Middle, L-Lower, LSD value is for means comparison along the columns
Treatments:
CP1: Maize and Bean intercrop in the upper and lower zones and sole maize in the middle
CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle
CP3: Sole maize crop in all the three zones
CP4: Maize and beans in all the three slope positions (farmers' practice)
CP5: Intercrop of maize and beans in upper, middle and lower zone.

Cropping patterns had no effect on P grain uptake, however, CP4 four had the least P grain uptake in all seasons (2049, 2029, 2081 ppm), respectively compared to the rest of the treatments. This observation was attributed to the absence of terrace embankment that would have caused the accumulation of moisture and sediments at the lower slope position for improved uptake. There were no observed differences in P grain uptake with seasonality. This observation was attributed to the absence of terrace embankment that would have caused the accumulation of moisture and sediments at the lower slope position. There were no observed differences in P grain uptake with seasonality.

4.3.6 Potassium uptake in maize grain

There were significant differences ($p \leq 0.05$) in maize grain K uptake as affected by slope positions in all seasons (Table 4.7). The lower slope position had on average 1343 ppm more K uptake than the upper position. This observation could be attributed to the spatial redistribution of surface runoff resulting in higher soil water availability on lower slope positions, which contributed to the higher amounts of K available at the lower slope position which resulted in enough nutrients for plant growth and accumulations of K and other nutrients in aboveground plant parts and therefore increase in K grain content. Also observed was the higher K uptake at all slope position in season one, and two which compared to season three may have been occasioned by higher rainfall experience in season one (450 mm), season two (416 mm) and season three (141 mm).Cropping patterns had no effect on K grain uptake in both seasons. However, cropping pattern three had 3316 ppm K uptake more than CP4 in season three which recorded 2663 ppm

Table: 4.7 Effect of season, slope position and cropping patterns on maize grain K (ppm) uptake

Season	I						II						III						Mean of means
Slope	CP1	CP2	CP3	CP4	CP5	Mean	CP1	CP2	CP3	CP4	CP5	Mean	CP1	CP2	CP3	CP4	CP5	Mean	
U	4100	4166	4150	3700	4066	4036	4063	3900	4033	3600	3913	3902	2533	2516	2550	2250	2500	2470	3469
UM	4233	4150	4150	3750	4233	4103	4200	3950	4200	3500	4233	4017	2853	2833	3000	2450	3000	2827	3649
M	3883	*	3800	3433	4000	3779	3866	*	3900	3366	3933	3766	2666	*	2766	2650	2766	2712	3419
LM	4441	4451	4498	4045	4445	4376	4425	4348	4505	4045	4408	4346	3477	3433	3700	2833	3433	3375	4032
L	5150	5666	5936	4366	5200	5264	5083	5283	5800	4383	5183	5146	4177	4150	4566	3133	4100	4025	4812
	4361	4608	4507	3859	4389		4327	4370	4488	3779	4334		3141	3233	3316	2663	3160		

*=Bean plot

CV(%) = 7.6, LSD$_{(0.05)}$= 456, SE(TREATMENTS)=231, SE(SEASONS*CROPPING PATTERNS*SLOPE POSITION*DEPTH)=163
U-Upper, M-Middle, L-Lower, LSD value is for means comparison along the columns
Treatments:
CP1: Maize and Bean intercrop in the upper and lower zones and sole maize in the middle
CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle
CP3: Sole maize crop in all the three zones
CP4: Maize and beans in all the three slope positions (farmers' practice)
CP5: Intercrop of maize and beans in upper, middle and lower zone.

These findings are in agreement with those of (Changere and Lal, (1997) who reported greater nutrient uptake in the lower slope position. Li *et al.*, (2009) reported that the total N absorbed by the plant in a semiarid region depend greatly on the amount of moisture stored in the profile at planting, as well as on the amount of rainfall during the growing period. A very closely linear relationship has been found between water content and mineralized N. Adequate soil water content significantly transfer a large portion of N to aboveground plant parts, and increase N contents in seeds. This study also found higher levels of moisture at the lower slope position at all the investigated growth stages (germination 17%, 9^{th} leaf stage 15.9% and at tasselling 15.5%) which may have given rise to the higher N uptake by grain at this slope position.

Hussaini *et al*., (2008) found that P uptake is enhanced when in combination with ammonium N (NH4-N). Nitrogen x phosphorus interaction was significant for P concentration and N accumulation in maize grain. As the NH4-N undergoes nitrification, P uptake and those of other elements are increased. Likewise, this study found on average higher amounts of N (1.53%) P (2664 ppm) and K (4564 ppm) in the lower slope position compared to N (1.26%), P (1926 ppm) and K (3357 ppm) in the upper slope position with lower moisture content.

Terraced fields are important for water and soil conservation in hilly–gully loess plateau areas in arid and semi-arid regions of China. Terracing results show remarkable increases in soil moisture storage and soil fertility, especially in the 40–180 cm depth. So, during the dry season, crops can absorb more water than in sloping land, thus increasing the uptake of deep moisture, nutrients and reducing evaporation losses (Liu, *et al*., 2011). Moisture reading from this study established that there was comparably higher soil moisture content in the lower slope position at the 50 cm (14.1%) and 75 cm (15.5%) depth in all the four seasons at tasselling. The higher soil moisture at this slope position positively influenced nutrient availability and uptake. Terracing changes the condition for crop growth for the fact that the runoff is prevented and the available water and heat is better utilized. Terracing also increases the moisture and nutrient use efficiencies (Jiao, *et al.*, 1999) which effectively enhances crop endurance to droughts and consequently increases crop yield. Accordingly, terracing improves the local agricultural environment and the carrying capacity. Jiao *et al*., (1999), further reported that for a single rainfall event of 95 mm, with an average rainfall intensity of 0.075 mm/min and maximal intensity of 1.2 mm, the terrace water retention rate was 92% and for a rainfall event of 150 mm with an average intensity of 0.075 mm/min, there was no water or soil loss from the terrace, and when it rained for 20 consecutive days, giving a total of 131.2 mm, the loss rate of water and soil was only 1.0% (Jiao *et al.*, 1999). Therefore, this soil moisture retained in the terraced land facilitates nutrient uptake by mass flow and diffusion which depend on soil moisture availability.

4.4 Crop height, number of leaves, LAI, above ground biomass and grain yields

4.4.1 Maize plant height at 9th leaf stage

There were significant differences ($p \leq 0.05$) in maize height as affected by slope positions and cropping patterns in all the seasons (Fig. 4.6). Plant height on average was highest at the lower slope position (122cm), followed by the lower middle position (97cm) and the upper middle position (83) respectively. The upper (74cm) and middle (75) slope positions had the shortest maize plants.

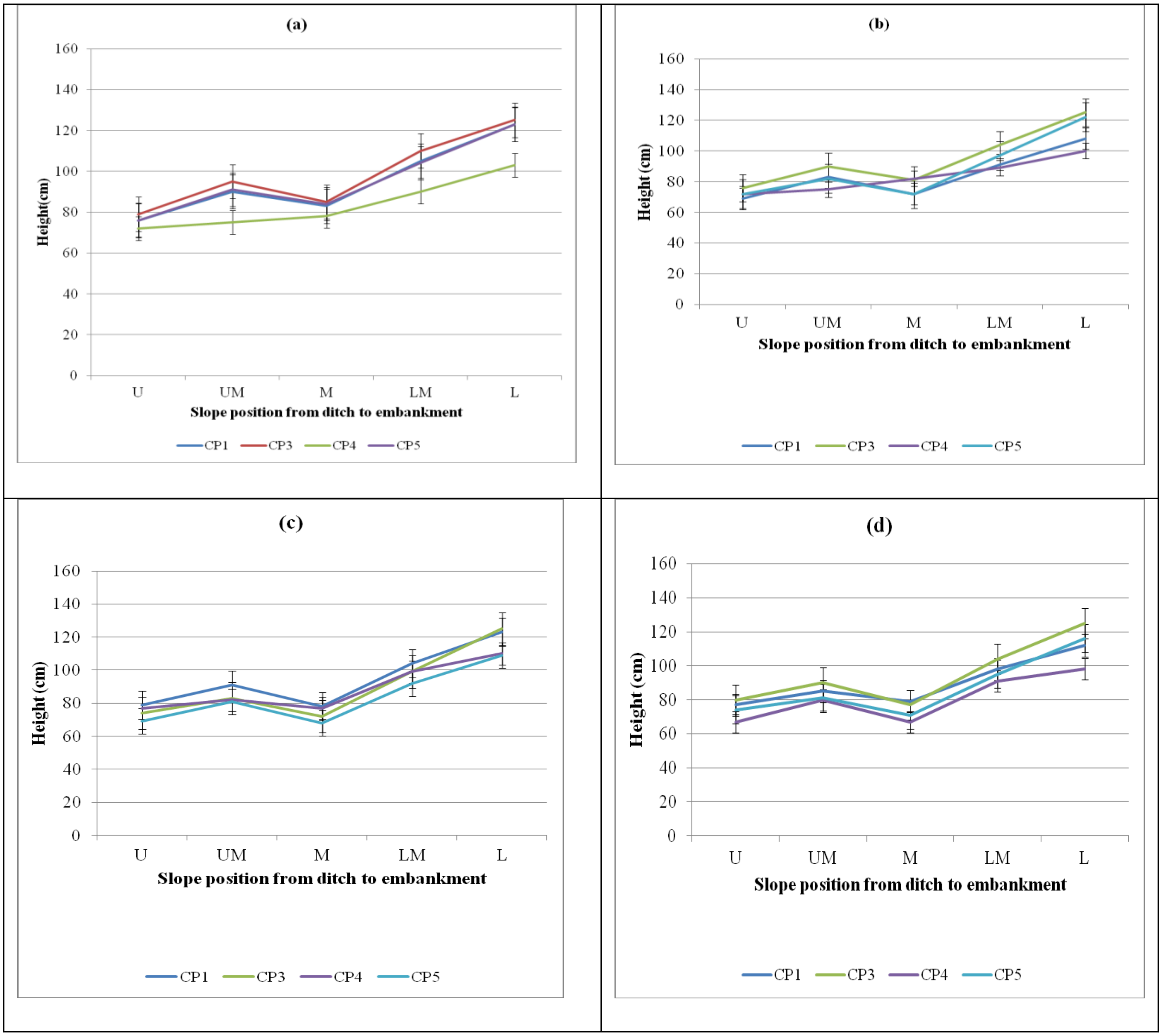

Figure 4.6 Maize height (cm) at 9th leaf stage in first season (a), second season (b), third season(c) and fourth season(d).

Key: U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower, (LSD $_{0.05}$)

Treatments:

CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle
CP3: Sole maize crop in all the three zones
CP4: Maize and beans in all the three slope positions (farmers' practices)
CP5: Intercrop of maize and beans in upper, middle and lower zone.

4.4.2 Maize plant height at tasseling

There were significant differences ($p \leq 0.05$) in maize height as affected by slope positions and cropping patterns in all the seasons (Table 4.8 and plate 4.2). The lower slope position had on average maize heights over 180 cm whereas the upper position had below 130 cm. The upper middle slope position had height (151 cm) more than both middle (142) and upper (125 cm) slope position.

Table: 4.8 Effect of season, slope position and cropping patterns on maize height (cm) at tasseling

Slope	Season I						Season II					
	CP1	CP2	CP3	CP4	CP5	Mean	CP1	CP2	CP3	CP4	CP5	Mean
U	133	131	136	125	134	132	126	129	133	106	131	125
UM	157	150	155	135	157	151	155	153	160	128	159	151
M	148	*	144	143	148	146	136	*	148	137	139	140
LM	180	169	176	152	170	169	168	174	173	150	175	168
L	199	195	196	164	196	190	180	187	187	162	182	180
Means	163	161	161	144	161		153	181	160	137	158	

Slope	III						Season IV						Means of means
	CP1	CP2	CP3	CP4	CP5	Mean	CP1	CP2	CP3	CP4	CP5	Mean	
U	120	117	122	124	120	121	104	102	104	102	110	104	120
UM	138	133	138	131	132	135	120	120	124	118	124	121	139
M	128	*	130	136	125	130	118	*	115	114	118	116	133
LM	148	148	150	144	147	148	134	133	134	130	134	133	154
L	163	166	166	151	165	162	143	143	144	140	144	143	169
Means	139	139	141	137	138		124	125	124	121	126		

*=Bean plot

CV(%) = 3.7, $LSD_{(0.05)}$= 4.937 , SE(TREATMENTS)=0.56, SE(SEASONS*CROPPING PATTERNS*SLOPE POSITION)=2.52

U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower, LSD value is for means comparison along the columns

Treatments:

CP1: Maize and Bean intercrop in the upper and lower zones and sole maize in the middle

CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle

CP3: Sole maize crop in all the three zones

CP4: Maize and beans in all the three slope positions (farmers' practices)

CP5: Intercrop of maize and beans in upper, middle and lower zone

The highest heights recorded for the lower slope position is due to the presence of moisture and nutrients caused by erosion upslope and sedimentation at this slope position. The higher height for the crops in the upper middle position was occasioned by the suitable environment created by the lateral seepage of water from the terrace ditch hence making nutrients available for the crops. The nutrient uptake by both grain and above ground biomass was higher than that for plants in both the middle and upper slope positions (Section 4.3. The lower slope position is the zone of moisture accumulation and sediment deposition at the embankment, making the soils richer in nutrients which are availed to the plants by the presence of adequate moisture. In addition there is a possibility that the soils here could be deeper hence better water storage. Elsewhere in this study it was observed that there were higher amounts of soil carbon, total nitrogen, available potassium and phosphorus in this slope position (section 4.2). The presence of water therefore facilitated the interaction of these nutrients resulting better uptake and efficient use hence the higher heights and general crop performance. The improved availability of nitrogen may have caused rapid cell division and elongation, hence the improved plant height

Plate 4.2 Maize height at tasseling: Note the height near terrace ditch and at the Embankment

Cropping pattern four had the lowest (121 cm) height while patterns one and three had the greatest heights across all seasons. The lowest height recorded for CP4 (control) could have been occasioned by the absence of the terrace embankment which would have encouraged the settling and infiltration of moisture in the other treatments, hence this cropping pattern experienced lower moisture storage and nutrients accumulation due to loss through runoff.

The general observation was that vegetative and generative performances of maize planted in terrace were higher than that of control (non-terrace). All differences among the observed maize performance were statistically significant. Similar results were obtained by Husain *et al.,* (2013) who reported that Plant height observed from 36 to 65 days after sowing revealed that plant height at the terrace plot was higher than that of control. The highest plant at terrace plot was156.6 cm while for control was 73.92 cm. These results were also supported by Shakeel *et al.,* (2014) who reported that maize grown on ridges recorded 7.2% higher heights than for those non-terraced sowing and attributed the observation to combined effects of soil nutrition and environmental conditions under which it was grown

The study revealed significant enhancement in plant height at the lower middle and lower slope position occasioned by moisture and nutrient availability resulting in improved availability of nitrogen which may have caused rapid cell division and elongation, hence the improved plant height. The upper and middle slope position recorded lowest plant height respectively, this could be attributed the fact that these positions are at the moisture and nutrient loss zones due to erosion, while the upper middle position is benefiting from lateral seepage from the terrace ditch. Cropping pattern four (control) had the lowest height across all seasons. This observation was probably due to the absence of the terrace ditch which encouraged lateral seepage at the upper middle slope position and terrace embankment which promoted the settling and infiltration of moisture at the lower middle and lower slope position, hence the lower heights recorded.

4.4.3 Leaf area index at 9th leaf and at tassling

The effect of slope positions and cropping patterns on maize leaf area indices was evident across all the seasons (Fig: 4.7 and 4.8) and at both 9th leaf and at tasseling stage.

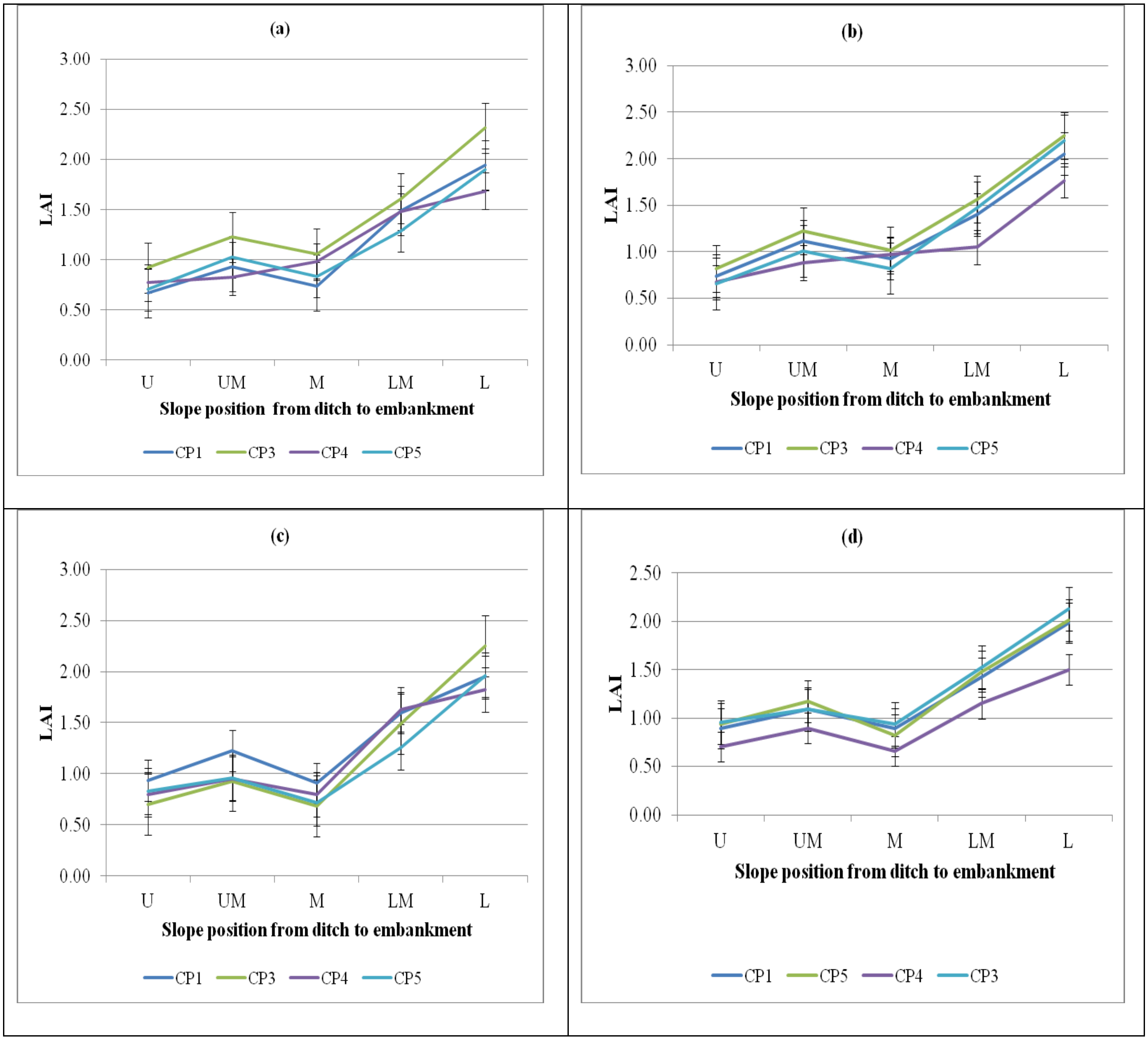

Figure 4.7 Maize LAI at 9th leaf stage in season I (a), season II (b), season III(c) and season IV(d). Key: U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower ($LSD_{0.05}$)

Treatments:
CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle
CP3: Sole maize crop in all the three zones
CP4: Maize and beans in all the three slope positions (farmers' practices)
CP5: Intercrop of maize and beans in upper, middle and lower zone

There were significant differences ($p \leq 0.05$) in LAI of maize as affected by slope position and cropping pattern at 9th leaf stage (Fig.4.7 and 4.8). The lower slope position had on average the highest LAI (2.35 1.95 at 9th leaf stage and 3.69 at tasseling stage) whereas the upper position had the least (0.79 at 9th leaf stage and 1.34 at tasseling stage). The upper middle slope position recorded higher (1.03 and 2.01) LAI compared to both the middle (0.84 and 1.73) and upper (0.79 and 1.34) slope position in all the four seasons.

In all the four seasons the LAI in the upper middle slope position was on average higher than in the middle and upper position in both crop stages (9th leaf and tasseling stages). This largely could be attributed to availability of moisture occasioned by lateral seepage from the terrace ditch in the upper middle position and sediment deposition, moisture and nutrient availability at the terrace embankment, which could have resulted in improved translocation of nutrients and water and improved root growth which probably enhanced leaf area duration as well as size of leaf hence the higher LAI. Thus, with the optimum supply of moisture and nutrients, the basic infrastructural frame and photosynthesis production efficiency of leaves were improved. The generally lower LAI indices in season III and IV was occasioned by low rainfall received compared to season I and II (450 mm in season I, 416 mm in season II, 141 mm in season III and 92.4 mm in season IV). The results agree with those of Gul *et al,* (2015) and Amin *et al.,* (2006), who found that ridge sowing of maize resulted in higher leaf area index of at different stages, which was attributed to improved water and nutrient availability due to loose fertile soil on the ridges, resulting better uptake of nutrients especially nitrogen.

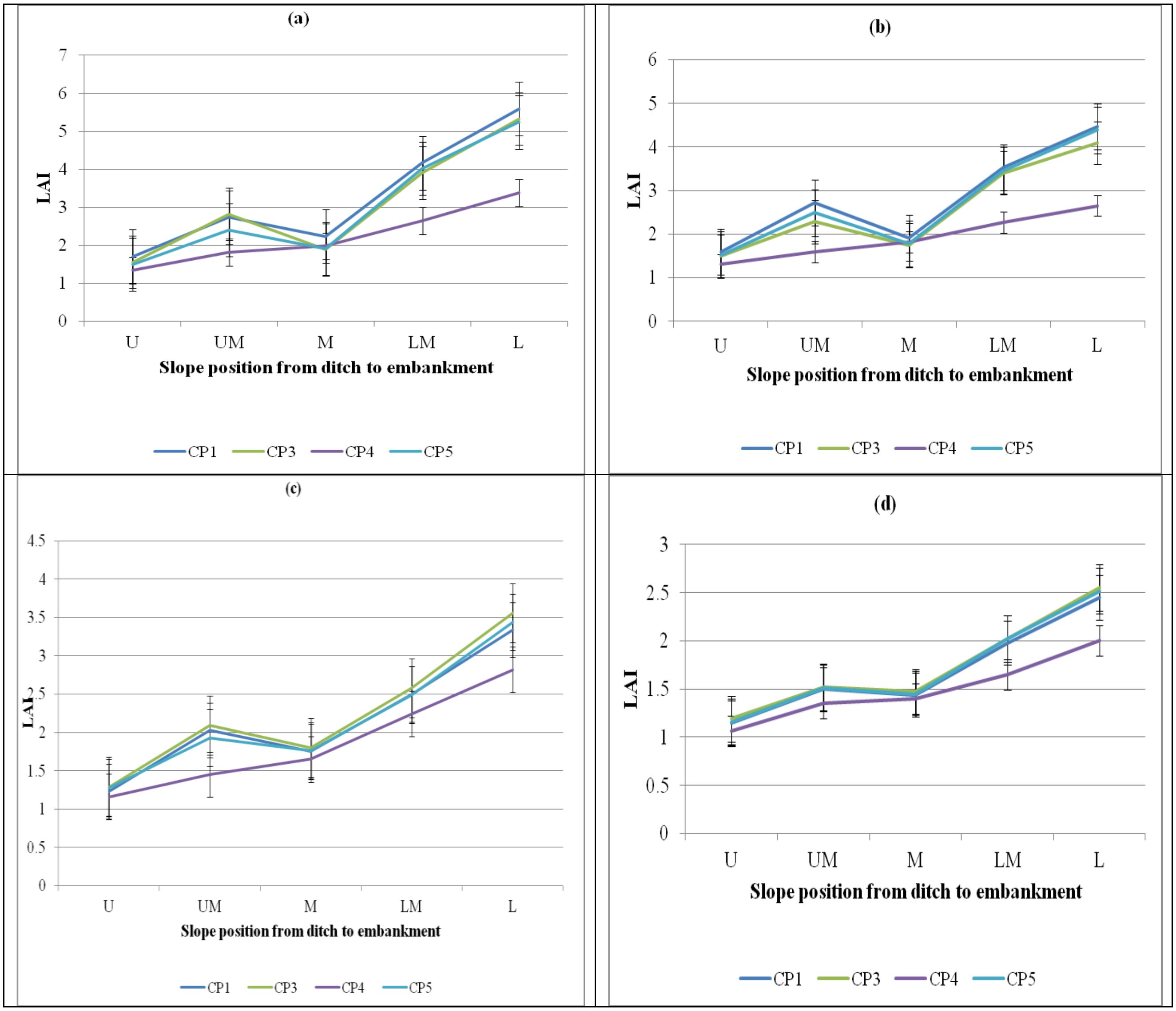

Figure 4.8 Maize LAI at tasseling season I (a), season II (b), third season III(c) and season IV (d).

Key:U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower (LSD$_{0.05}$)

Treatments:

CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle
CP3: Sole maize crop in all the three zones
CP4: Maize and beans in all the three slope positions (farmers' practices)
CP5: Intercrop of maize and beans in upper, middle and lower zone.

The availability of sufficient nitrogen is linked to rapid cell division and cell elongation thereby resulting in increased leaf area. Shivay and Singh (2000) also found improvement in leaf area index with increasing levels of nitrogen.

4.4.4 Number of leaves in maize

There were significant differences ($p \leq 0.05$) in the number of leaves in maize as affected by slope positions and cropping patterns in all the seasons (Fig. 4.9).

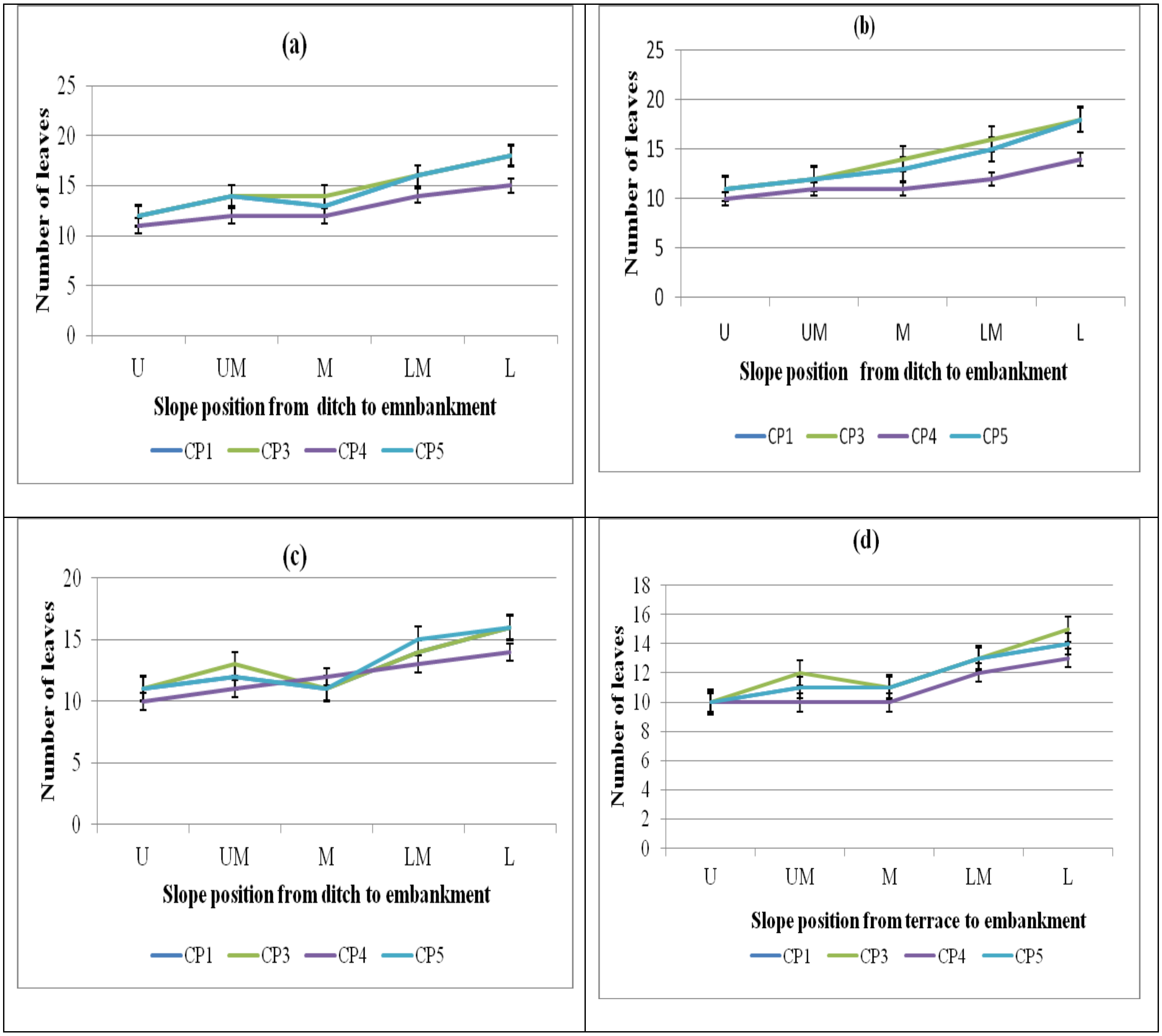

Figure 4.9 Number of leaves in maize at tasseling season I (a), season II (b), season III(c) and season IV(d).
Key: U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower (LSD $_{0.05}$)
Treatments:
CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle
CP3: Sole maize crop in all the three zones
CP4: Maize and beans in all the three slope positions (farmers' practice)
CP5: Intercrop of maize and beans in upper, middle and lower zone

The lower slope position had on average over 15 leaves, followed by the lower middle with 14 leaves while the upper position had below 11 leaves on average. The upper middle position recorded higher leaf count (12 leaves) than both the middle and upper slope positions. These findings tend to indicate that availability of nutrient and moisture improved the vegetative growth of the plant because the plants in the moisture and nutrient deficient zones namely upper and medium slope positions recorded the lower leaf count. The higher number of leaves in the lower middle and lower slope position could therefore be associated with the accumulation of moisture and sediments. This accumulation may have resulted in the improved availability of nutrients especially nitrogen and phosphorus.

The vegetative growth of plants is greatly affected by the moisture stress. Nitrogen is primarily responsible for vegetative growth, while P is involved in among other functions, photosynthesis and nutrient movement within the plant. P deficiency results in a reduction in leaf expansion and leaf surface area, as well as the number of leaves. The low number of leaves in the loss zones and in the control plot can therefore be explained by the low moisture and nutrient accumulation. Similar results were reported by Husain, *et al*, (2013), who found that the leaf number of terrace plot was higher than that of non-terrace while the leaf number variability of terrace plot was slightly broader than that of control. Highest leaf number of terrace plot was 12 leaves while for control was 8.17 leaves.

4.4.5 Maize above ground biomass yields

There were significant differences ($p \leq 0.05$) in maize above ground biomass yields as affected by slope position and cropping pattern in both seasons (Fig. 4.10). Cropping pattern three had the highest (7.5 tha^{-1}) aboveground biomass yield whereas pattern four yielded the lowest (4.8 tha^{-1}) biomass in season I. The lower slope position had the highest (> 6 tha^{-1}) yield of maize above ground biomass as compared to the upper slope position (< 4 tha^{-1}) in both seasons (Fig. 4.10). The upper middle slope position had higher (5 tha^{-1}) above ground biomass yield than the middle (4.2 tha^{-1}) and upper (3.8 tha^{-1}) positions. Biomass production is the function of productive potential of a particular site or edaphoclimatic conditions. The higher above ground biomass yields in the lower middle and lower slope position could be associated with the accumulation of moisture resulting in not only the availability of nutrients but also their synergetic interaction as the three main elements (N, P and K) have different functions which are enhanced when they work together. Nitrogen is primarily responsible for vegetative growth while P is involved in several key plant functions, including energy transfer, photosynthesis, transformation of sugars and starches and nutrient movement within the plant. When P is limiting, the most striking effects are a reduction in leaf expansion and leaf surface area, as well as the number of leaves. Potassium is associated with movement of water, nutrients, and carbohydrates in plant tissue. When K is deficient or not supplied in adequate amounts, growth is stunted and yields are reduced. This can therefore explain the low above ground biomass yield in the loss zones and in the control plot. The pattern created by above ground biomass yields is according to the nutrient and moisture accumulation. Season four had the lowest yields in above ground biomass across all treatments which could have been occasioned by the lower rainfall received that season (416 mm in season II and 92.4 mm in season IV). The results are in agreement with those of Nwachukwu and Ikeadigh (2012) and Hammad *et al.,* (2012) who reported that there was a linear relationship between water use, nutrient uptake and above ground biomass yield in maize crops. Plant productivity and above-ground biomass were found to increase with higher soil resources (e.g. nitrogen, phosphorus) and water availability.

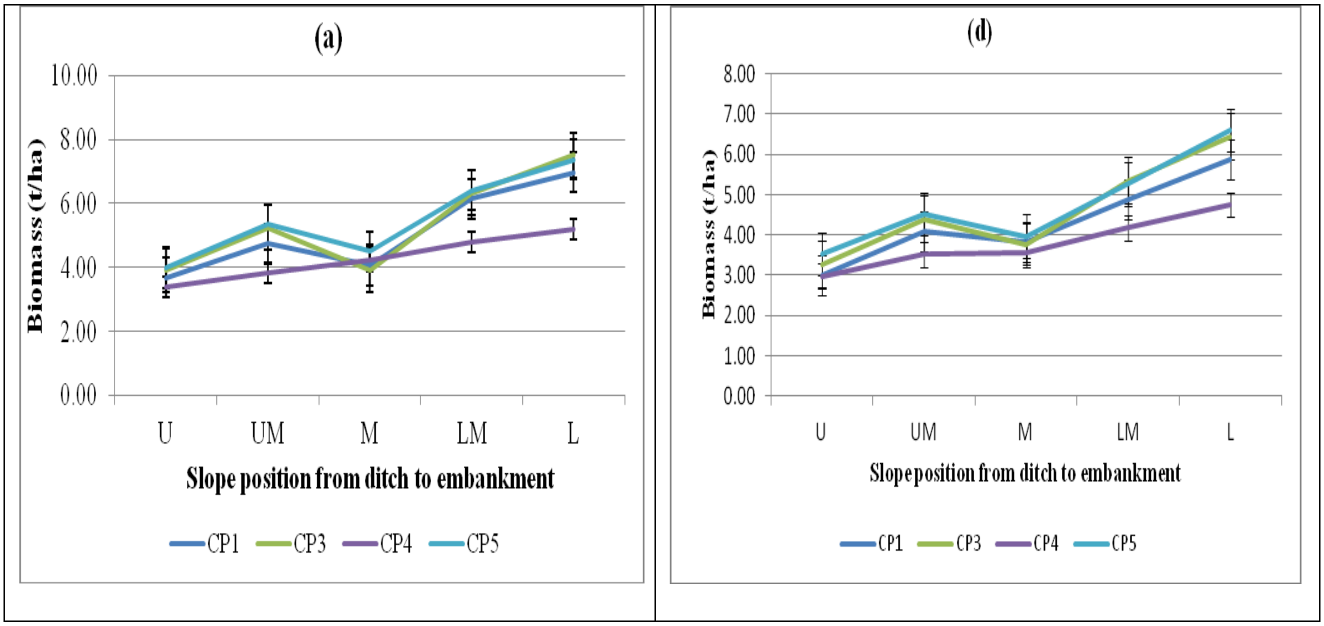

Figure 4.10 Maize above ground biomass yields in first season (a) and and fourth season(d).
Key-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower (LSD $_{0.05}$)

Treatments:

CP1: Maize and Bean intercrop in the upper and lower zones and sole maize in the middle
CP3: Sole maize crop in all the three slope positions
CP4: Maize and beans in all the three slope positions (farmers' practices)
CP5: Intercrop of maize and beans in upper, middle and lower slope position

Above ground biomass yield was 18.67 tha^{-1} with 169 mm of rain and 14.36 tha^{-1} with 120 mm in respective growing seasons in Vasto, Italy (Di Paolo and Rinaldi, 2008). In this study the yield was on average 6.82 tha^{-1} with 416 mm of rainfall in season II and 5.74 tha^{-1} with 92.4 mm of rainfall in season IV

4.4.6 Number of pods in beans

There were significant differences (p≤0.05) in number of pods in beans as affected by slope positions and cropping patterns in both seasons (Fig. 4.11). Cropping patterns, one, two, three and five had the highest (19) number of pods whereas pattern four had the lowest (12) pods in both seasons. The lower slope position had the highest (above 19) number of pods as compared to the upper slope position (below 7) in both seasons (Fig. 4.11). Like other yield parameters the number of pods per plants may have been dictated by the moisture and nutrient availability in the upper middle position occasioned by lateral seepage and at the lower middle and lower slope position by moisture and sediment accumulation. This deposition zones not only created a suitable environment for nutrient uptake, resulting in increased pod formation. It was also observed that there was a general decline in the number of pods in season III with the highest recording 15 pods on average in the lower slope position and 5 in the upper slope position compared to season I which 19 pods in the lower slope position and 8 in the upper slope position. This low number of pods can be associated with low availability of moisture in season three compared to season one occasioned by low rainfall of 92.4 mm. The control plot recorded on average the lowest number of pods (12) in both seasons, an observation that can be linked to the absence of zones of moisture and nutrient accumulation present in the other four treatments.

Similar results were reported by Barrios *et al*., (2005) who indicated soil water deficits that occur during the reproductive development of dry beans can decrease the number of flowers, pods and number of seeds per pod. The total number of flowers in beans may be reduced up to 47% therefore affecting the number of pods per plant. Pod abortion under moisture stress was also observed in a range between 21 and 65. Under stress, the decrease on the number of flowers and pods for some legumes, such as soybeans, was due to a great extent to a limited vegetative growth. The same is echoed by Emam *et al.*, (2010), who reported that plant height, number of leaves, leaf area, number of pods, pod dry weight and total dry weight of two common bean (*Phaseolus vulgaris* L.), Sayyad as an indeterminate and D81083 as a determinate cultivar. Both cultivars responded significantly to moisture stress conditions. Water stress also reduced plant height, number of leaves, leaf area and number of pods.

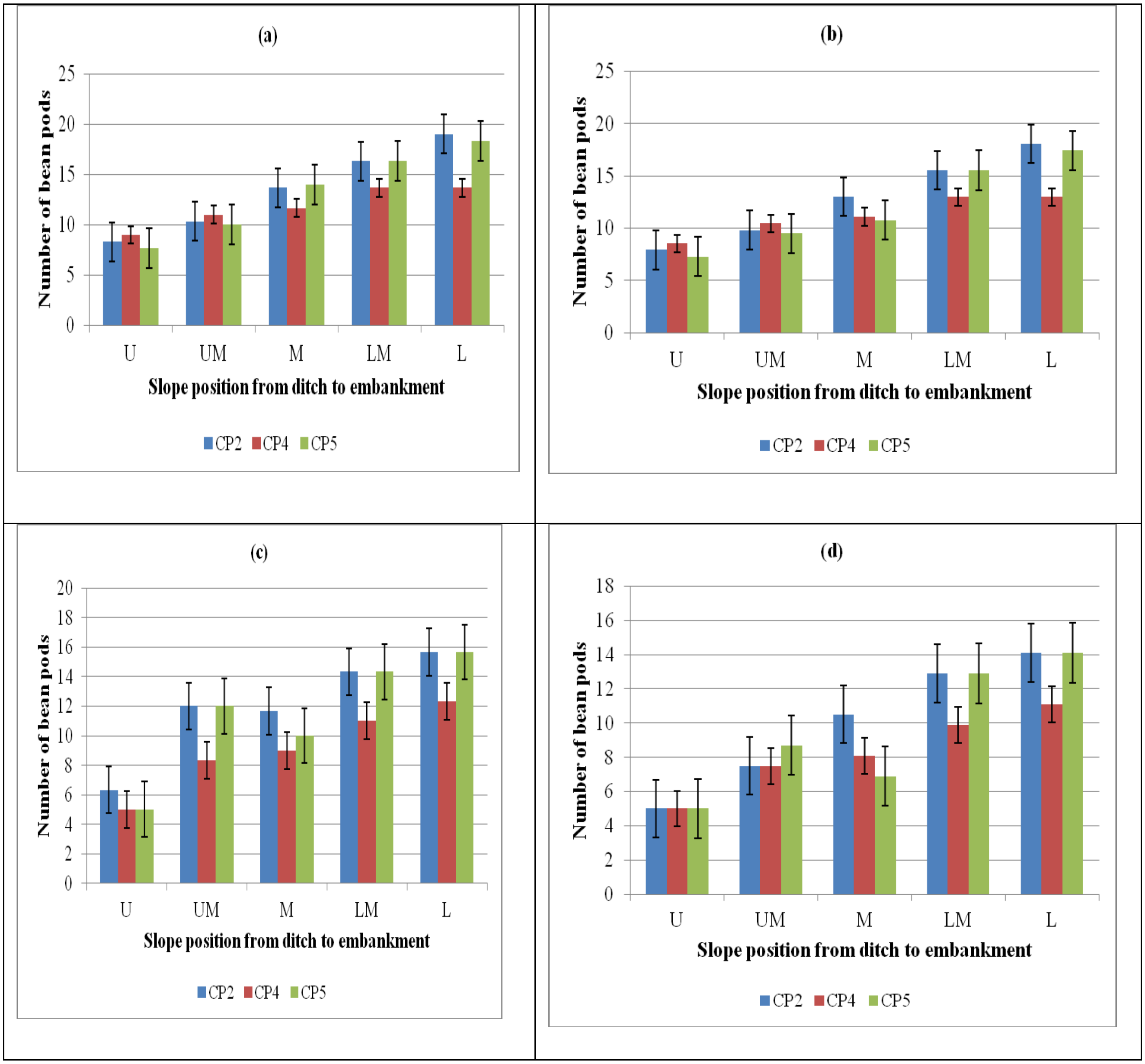

Figure 4.11 Number of bean pods in season I (a), season II (b), season(c) and season IV (d).

Key: U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower, LSD value is for means comparison along the columns

Treatments:

CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle

CP4: Maize and beans in all the three slope positions (farmers' practices)

CP5: Intercrop of maize and beans in upper, middle and lower zone.

4.4.7 Bean grain yield

There were significant differences ($p \leq 0.05$) in bean grain yields as affected by slope positions and cropping patterns in all seasons (Fig. 4.12)

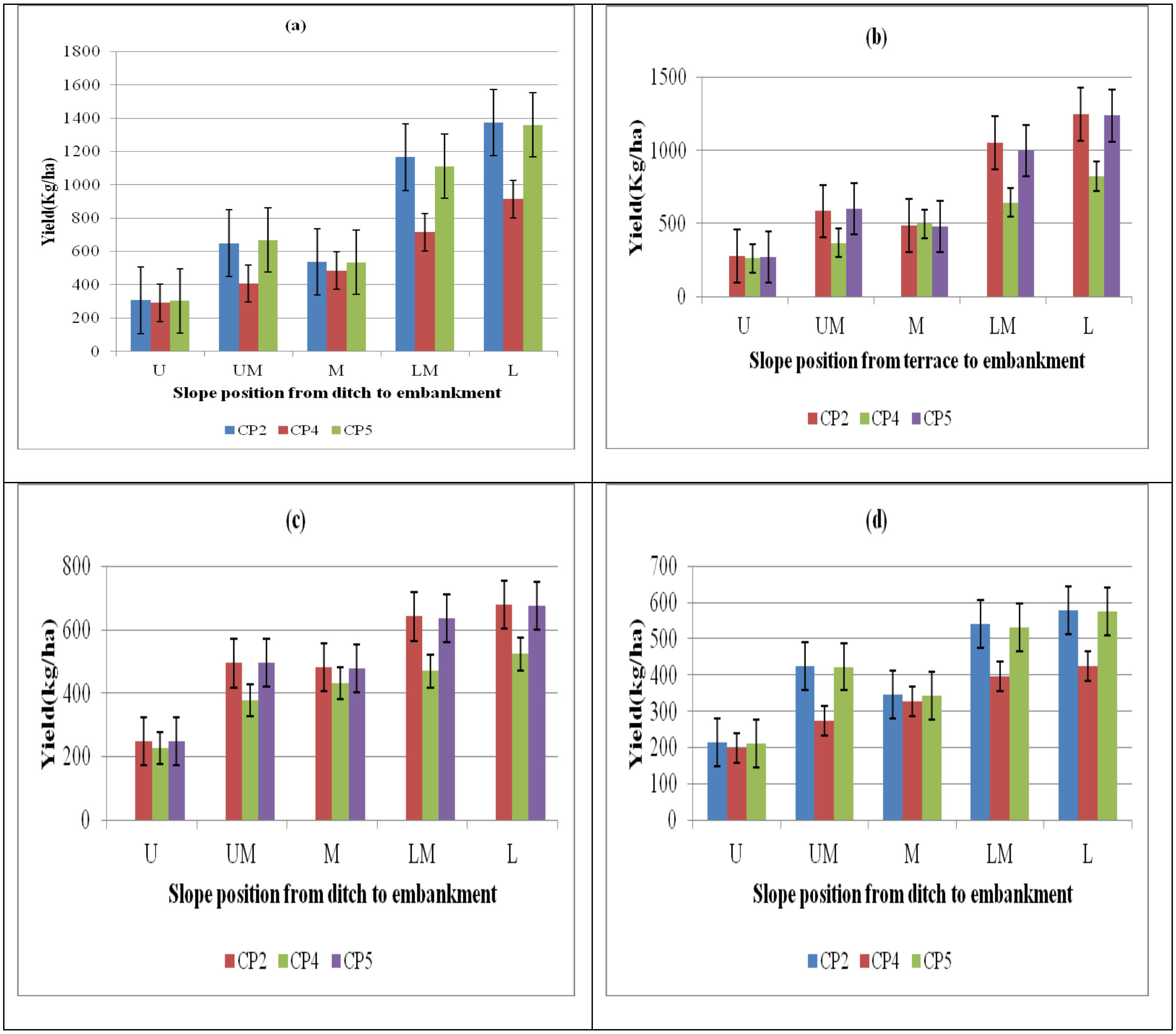

Figure 4.12 Bean yields in season I (a), season II (b), season III and season IV(d).

Key: U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower, LSD value is for means comparison along the columns

Treatments:

CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle

CP4: Maize and beans intercrop in all the three slope positions (farmers' practice)

CP5: Maize and beans intercrop in all the three slope positions

The lower slope position had the highest (above 1380 kgha^{-1}) bean grain yields, followed by the lower middle slope position with 1200 kgha^{-1} while the upper middle slope position recorded about 500 kgha^{-1} compared to the upper slope position (below 250 kgha^{-1}) and middle slope below 400 kgha^{-1} in all seasons (Fig. 4.12). Cropping patterns two, and five had the highest (1350 and 1250 kgha^{-1}) bean grain yields in season one and two whereas pattern four (control) had the lowest (900 kgha^{-1}), in the lower slope position. In the low rainfall season three (141 mm) and four (92.4 mm) the highest yields realised were 680 and 570 kgha^{-1} in the lower slope position compared to 250 and 220 kgha^{-1} in the upper slope position.

The higher yields recorded in the upper middle position, lower middle and lower slope position was occasioned by the availability of moisture leading to improved nutrient uptake and use by the plant. The results are echoed by Adelson and Teixeira (2008) who reported that continuous N and P uptake due to favourable rainfall distribution during early pod filling was responsible for higher grain yields of common bean. The lower yields in season three and four were associated with lower rainfall received compared to season one and two (450 and 416 mm respectively).

4.4.8 Maize grain yield

There were significant differences ($p \leq 0.05$) in maize grain yields as affected by slope positions and cropping patterns in both seasons (Fig. 4.13 and Plate 4.3). Cropping pattern three and two had the highest (5 and 4.8tha^{-1}) maize grain yields whereas pattern four had the lowest (3.6 tha^{-1}) on average in seasons one. The lower slope position had the highest (above 7.2 tha^{-1}) maize grain yields as compared to the upper slope position (below 3 tha^{-1} and 1 tha^{-1}) in season one and three (Fig. 4.13 and plate 4.3). The upper middle slope position continued to present on average higher (4.1 tha^{-1}) yields than the middle (3.5 tha^{-1} and 2.8 tha^{-1}) and upper slope positions in season one and two respectively. The higher yields recorded in these slope position was as a result of moisture and nutrient availability occasioned by deposition at the terrace embankment and lateral seepage which may have created a suitable environment for nutrient availability resulting in improved uptake of N which significantly improved maize yields. Moreover, higher leaf area index values noticed at these slope positions meant the production of more photosynthates leading to increase in grain number and weight of grains. The significant interaction between N and P on plant height and number of branches could be due to the importance of these nutrients in the growth and development of crops. The increased P uptake results in improved crop performance. Similar results were reported by Shehu *et al.,* (2009), who indicated that significant interaction of N x P x K on seed yield and dry matter could be due to nutritional balance that favours the functioning of each nutrient in the growth and development of crops. The lower yields recorded across seasons and slope position for treatment four (control), may be associated with the absence of both terrace ditch and terrace embankment which would have created the zones of moisture and nutrient accumulation found in the other treatments. The same could be explained for the upper and middle slope position which suffered loss of both moisture and nutrient due to erosion hence the low yields recorded. In general season three had lower yields compared to season one, this observation could be associated with the low reainfall in season three (141mm) compared to season one(450mm) resulting in restricted nutrient uptake by plants. The results are consistent with previous studies done on maize, where yield and soil moisture increased as one proceeded down slope, in addition to position along the slope nutrient availability was found to be an equally important factor (Earnshaw and Orr 2013). These findings are also in agreement with those of Changere and Lal (1997) who reported highest biomass production, greater nutrient uptake, and highest corn grain yield in the lower slope position. The mean corn grain yield in the lower position was 36.9% and 56.8% more than upper and middle landscape positions, respectively (Changere and Lal, 1997). Similarly in this study maize grains yield in the lower slope position was 50% more than the upper slope position and bean grain yields in the lower slope were about four times the yields in the upper slope position.

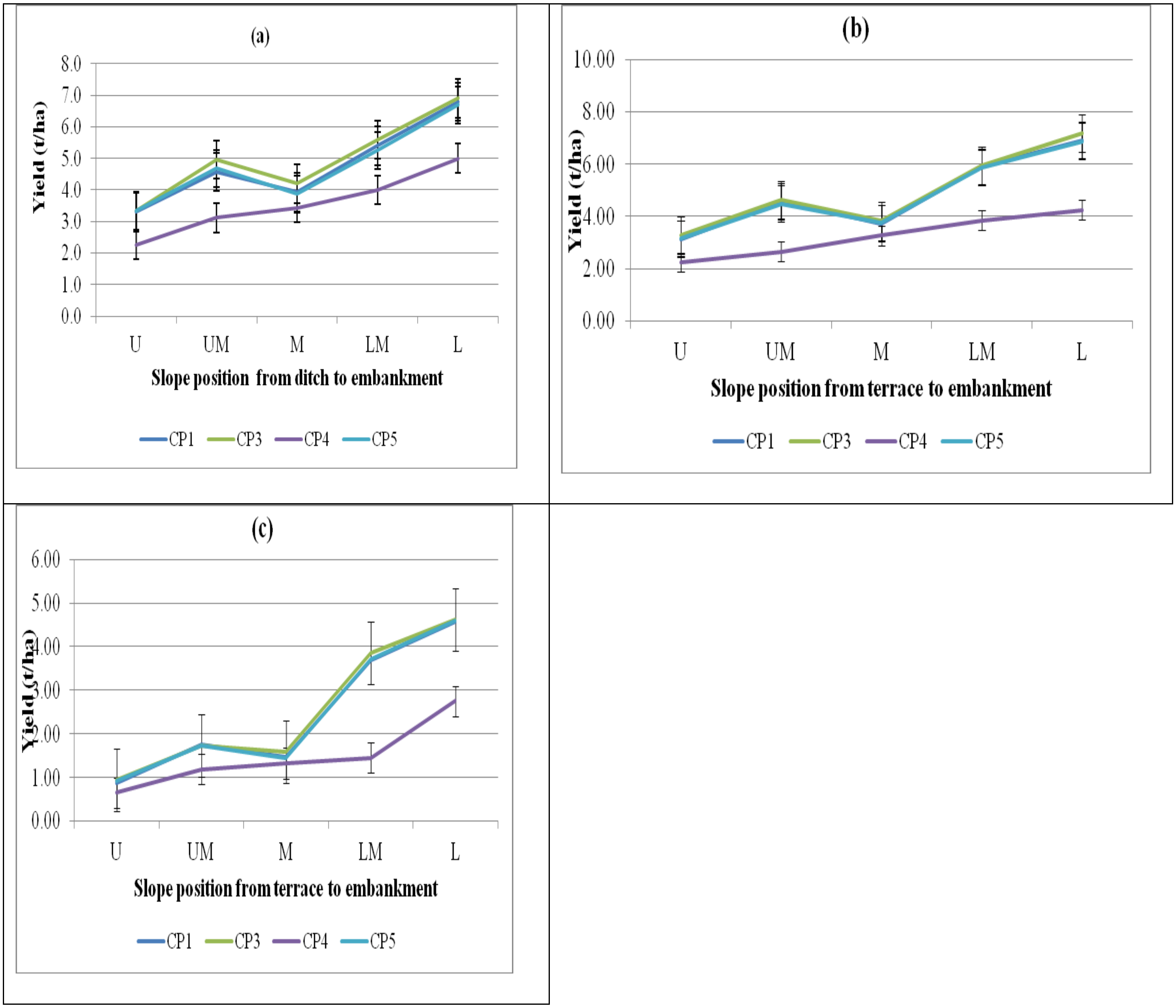

Figure 4.13 Maize grain yields in first season (a), second season (b) and third season(c)
Key:U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower, ($LSD_{0.05}$)

Treatments: CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle
CP3: Sole maize crop in all the three zones
CP4: Maize and beans in all the three slope positions (farmers' practices)
CP5: Intercrop of maize and beans in upper, middle and lower zone

Ovuka (2000) also reported that there were lowest grain yields on upper slopes, increasing steadily down slope to often double grain yields on the lower or base slopes especially where the soil conservation structures were not maintained, indicating massive transfer and deposition of nutrients. Similar resulted were obtained in this study, where maize crops in the lower slope position next to the terrace embankment had up to two cobs compared to one cob in the upper slope position (Plate 4.3).

Plate 4.3: Note the size and number of cobs near terrace ditch and at the embankment

Figueiredo (1986), in a field survey on the yield of food crops on terraced and non terraced land in Kangundo , Machakos county reported that there was a significant increase in yield on terraced land compared with those without terraces. The average yield was 1601kg/ha of dry grain (about 20% m.c) for terraced and 1124 kg/ha for non-terraced, an increase of 42%. He further reported that in dryer maize-sunflower zone (UM-4), the mean yield was 1854 kg/ha for farms with terraces and 1047 kg/ha for non- terraced. The difference in yield of 77% was highly significant at ($P \leq 0.01$). These results, like the findings obtained in this study indicated that there was a positive effect on yields by terracing especially in the drier areas. The main objective of this study was not only to identify the zones of moisture and nutrient accumulation but also to develop an appropriate cropping pattern in the terraced fields that will maximally take advantage of the nutrient and moisture variability for improved yields. The most appropriate cropping pattern will be promoted for adoption by farmers, who have continued to grow their crops in the terraced farms without taking account these variabilities.

Similar findings were reported by Gebremedhin *et al.,* (2009) in a study in Tigray, Northern Ethiopia, to determine the yield and farm profitability impact of stone terraces. In this study seventy terraced and 70 non-conserved plots were equally divided between wheat (*Triticum aestivum*) and fava beans *(Vicia faba*). Results indicated that grain and straw yields for both crops were significantly higher in the soil accumulation zone than in the soil loss zone or in the non-terraced control plots and that grain and straw yields from the soil accumulation zone were more stable than those from control zone (Gebremedhin *et al.,* 2009). The comparison on grain number showed that the grain number of terrace plot was higher (486) than that of control (218) and in addition the weight of 100 dry grains was higher for terrace plot (29 g) compared to that (24 g) of control (Husain *et al.,* 2013).

The performances of major crops grown at Anjeni watershed in Ethiopia were evaluated at loss, middle and deposition zones of the terraces by measuring yield and yield components. There were highly significant differences ($p \leq 0.01$) among the treatments for all crop parameters for wheat and maize (Amare *et al.*, 2013). Farmers of Anjeni watershed also noted that the lower parts of the terraces were usually more fertile than the upper ones and they used the upper parts for growing a less nutrient demanding crops such as triticale (*Triticale hexaploide* Lart) while the lower part for relatively higher level of nutrient demanding crops like teff (*Eragrostis teff*) and wheat (*Triticum aestivum*) (Amare *et al.,* 2013). The accumulation zone was found to have significantly higher ($p \leq 0.01$) mean value of grain yield than that of middle and loss zones with mean value of 1077.23, 759.93 and 656.19 kg ha^{-1}, respectively (Amare *et al.,* 2013). Enyew and Akalu (2010) also found higher yield from conserved areas that were changed to bench terraces than non-conserved neighbouring farmlands. Similarly, Tadele *et al*., (2011) obtained higher yield from the accumulation zone than loss zone. The differences between deposition, loss and middle zones of terrace upon the yield and yield components of maize were also statistically significant ($p \leq 0.01$). Higher grain yield was recorded at the deposition zone or lower slope followed by middle and upper slopes with grain yield value of 2695.10; 1685.90 and 1072.90 kg ha^{-1}, respectively and the total biomass and plant height showed significant differences between landscape positions (Tadele *et al*., 2011) at $p \leq 0.01$. Similarly in this study, the lower slope position had on average 5423 kg/ha, followed by the lower middle and upper middle slope position, 4097 kg/ha and 3256 respectively. The least values were realised for the middle 2723 kgs/ha and upper slope position 2213 kgs/ha. According to Rockström and De Rouw (1997), upslope suffered more during periods of water shortage, systematically for all yield components subject to a water shortage (11% lower number of pan. hill-' in 1994, 31% lower grain number in 1996, and 8% lower grain mass in 1995, compared to down slope. Higher soil water availability down slope, as a result of redistribution of surface overland flow, was a contributing factor to these yield gradients. In West Africa pearl millet is grown on the degraded uplands, sorghum on mid-slopes, and maize and sorghum on the soil water rich lower slopes down to the lowlands (Rockström and De Rouw, 1997). The slope variability observed here favours a flexible response to water shortage, enabling the crop to escape from periods of drought. Field scale variability and toposequence effects on crop growth can, therefore, be seen as a strategic part of the farmer's efforts towards risk reduction, rather than solely as an obstacle to yield increases.

Spatial variability can also be exploited in favour for increased crop production, as shown for soil properties when using site specific precision farming (Bouma *et al*., 1995). The observations indicate a correlation between rainfall distribution and the performance of yield components, and a timing of leaf growth to soil water availability. If analysed on a yearly basis, the results indicate that primarily nutrients and not water determine final yield. But if analysed on the basis of yield components the results suggest that water and nutrients interact during each growth phase, for all fertility levels (Bouma *et al*., 1995). In this study moisture and nutrients were found to interact as water in form of moisture facilitated the uptake and efficient use of nutrients as indicated in both nutrient uptake in above ground biomass and in nutrient accumulation in grain. A study in the West Usambara Highlands Tanzania, showed a significant increase in the crop yield for maize and beans by implementing bench terraces, *fanya juu* or grass strips (Tenge *et al*., 2005). However, the results clearly showed that cross-slope barriers alone may not significantly increase crop yields unless these are followed by other practices such as manure and fertilizer application. Grass strips and / or the introduction of grass on the terrace risers, can lead to an additional increase in yield which can be either used as fodder for livestock or it can be sold (Tenge *et al*., 2005).

4.5 The profitability of maize and bean production under different cropping patterns in a terraced field

The results indicate that slope position and cropping pattern had an effect on yields and the eventual gross margins. The lower slope position had the highest gross margins (Kshs. 196,331/ha, and 100,265/ha) whereas the upper position had the least margins (133,924 and 25,714) for maize and beans respectively (Tables 4.13 and 4.16). Cropping pattern four (farmers practice) had the least gross margins (Kshs. 84641 for maize and 46025 for beans) compared to CP3 (Kshs. 120,551 for maize and CP2 (Kshs. 62705) for beans, (Tables 4.14 and 4.15). The gross margins were done to determine the most profitable slope position as well as the cropping pattern that would gives the highest gross margins.

Table 4.9: Variable costs

S/N	Item	Unit cost (kshs)	Total Cost/1350m^2 (Kshs)	Total Cost/ha (Kshs)
1.	Establishment of terraces	7,700	7,700	57037
2.	Maintenance of terraces	600	600	4444
3.	Land preparation	900	1,800	13333
4.	Planting	1,200	2,400	17778
5.	Weeding	1,200	2,400	17778
6.	Control of stalk borer	180	360	2667
7.	Maize seed	380	1,900	14074
8.	Bean seed	400	2,000	14815
9.	Fertilizer DAP	2,500	5,000	37037
10.	CAN	1,800	3,600	26667
11.	**Total variable costs**		**27,760**	205630

Table 4.10: Bean grain yields per slope positions per season

Slope position	Season I	Season II	Season III	Season IV	Average yields (kg/ha)	Unit Price (Kshs)	Average income (Kshs)
Upper	199	188	158	105	163	120	19560
Upper middle	286	275	228	205	249	120	29880
Middle	260	240	149	145	199	120	23880
Lower middle	1062	951	638	595	812	120	97440
Lower	1166	1050	843	775	959	120	115080
Average	595	541	403	365	476	120	57120

Table 4.11: Bean grain yields per cropping pattern per season

Cropping Pattern	Season I	Season II	Season III	Season IV	Average yields (kg/ha)	Unit Price (Kshs)	Average income (Kshs)
C P 1	648	565	408	214	459	120	55080
C P 2	655	654	409	429	568	120	68160
C P 4	428	395	379	391	398	120	47760
C P 5	650	550	416	427	511	120	61320
Average	595	541	403	365	476	120	57120

Table 4.12: Maize grain yields per slope positions per season

Slope position	Season I	Season II	Season III	Average yields (kg/ha)	Unit Price (Kshs)	Average income (Kshs)
Upper	2990	2750	900	2213	45	99585
Upper middle	4270	3887	1610	3256	45	146520
Middle	3530	3250	1390	2723	45	122535
Lower middle	4900	4780	2610	4097	45	184365
Lower	6050	5800	4420	5423	45	244035
Average	4348	4093	2186	3542	45	159390

Table 4.13: Maize grain yields per cropping pattern per season

Cropping pattern	Season I	Season II	Season III	Average Yields (kg/ha)	Unit Price Kshs	Average income (Kshs)
CP1	4540	4270	2235	3682	45	165690
CP2	4550	4275	2257	3694	45	166230
CP3	4590	4329	2298	3739	45	168255
CP4	3550	3325	1950	2941	45	132345
CP5	4510	4268	2190	3656	45	164520
Average	4348	4093	2186	3542	45	159390

Gross margins for maize = gross income-variable costs

Table 4.14: Gross margins(Ksh/ha) for maize as per slope position

Slope position	Total output **(Kshs)**	Total Cost **(Kshs)**	Gross margins **(Kshs)**
Upper	99585	47704	51881
Upper middle	146520	47704	98816
Middle	122535	47704	74831
Lower middle	184365	47704	136661
Lower	244035	47704	196331
Average	159408		111704

Table 4.15: Gross margins(Kshs/ha) for maize as per cropping pattern

Cropping pattern	Average output **(Kshs)**	Average Cost **(Kshs)**	Gross margins **(Kshs)**
CP1	165690	47704	117986
CP 2	166230	47704	118526
CP 3	168255	47704	120551
CP 4	132345	47104	85241
CP 5	164520	47704	116816
Average	159390		111824

Gross margins for beans = gross output-Total cost

Table 4.16: Gross margins(Ksh/ha) for beans as per cropping pattern

Cropping pattern	Total output **(Kshs)**	Total Cost **(Kshs)**	Gross margins **(Kshs)**
C P 1	55080	14815	40265
CP 2	68160	14815	53345
CP 4	47760	14215	33545
CP 5	61320	14815	46505
Totals	57120		43415

Table 4.17: Gross margins (Ksh/ha) for beans as per slope position

Slope position	Total output **(Kshs)**	Total Cost **(Kshs)**	Gross margins **(Kshs)**
Upper	19560	14815	4745
Upper middle	29880	14815	15065
Middle	23880	14815	9065
Lower middle	97440	14815	82625
Lower	115080	14815	100265
Totals	57168	14815	42353

The results indicate that the lower slope position, season and cropping pattern had an influenced on the yields and eventually the gross margins. The gross margins realised in the lower slope position were almost three times those of the upper slope position (Kshs. 196,331 and 51,881) for maize. These differences in gross margins were occasioned by the yields which were found to be highest in the lower slope position where moisture and nutrients were found to be more available. The higher maize gross margins in season I (Kshs.147,956) and II (Kshs.136,481) can be linked to the higher yields and rains realised in those two seasons compared to season III (Kshs.50,666) which had lower rains and yields. The gross margins of sole and intercrops did not show significant differences in all seasons. CP3 (sole maize) had comparable (Kshs. 120,551/ha) margins with intercrops, CP 1 and CP2 (Kshs. 117,986/ha and 118,526/ha). Meaning that farmers can take the advantage of intercrop and get two crops against one sole maize crop, especially in the drylands where moisture and soil fertility have continued to be a challenge. For beans the farmers practice (CP4) had Kshs. 32,945 compared to CP 2 (Kshs. 53,345 and CP 5 (Kshs. 46,505/ha). The gross margins showed that terracing plays an important role in improving crop yield resulting in higher gross margins.

According to Zhang, *et al (*1999), terraced fields reduce erosion rates by up to 80 percent. This progress in soil conservation does not only control soil erosion, it also produces economic benefits. For example, in this study the terraced plots had on average 21% higher yields than those of non-terraced plots. This indicates that terraces are effective for conserving soil and water, leading to increased productivity.

Terraces are however costly when large equipment is used and require large inputs of labour when constructed manually. McLaughlin (1993) reported that terracing of Loess Plateau land in Gansu Province required 900 labour-days per hectare, not including time for planting crops and for later maintenance. This level of investment is only feasible where land is extremely scarce and the need for food production is high. For this study the terraces were constructed and maintained manually at a price of Kshs. 61,441/ ha, though the cost could come down where labour is readily available. A cost benefit analysis was used to determine the economic benefits of *fanya juu* terraces and grass strips in Anjene watershed in Ethiopia. The analyses looked at benefits of with and without terraces, including gross and net profit values, returns on labour, water productivity and impacts on poverty. The results indicated that soil and water conservation had improved crop productivity. Using a discount rate of 10%, the average net present value (NPV) of barley production with terrace was found to be about US$ 1542 over a period of 50 years. In addition, the average financial internal rate of return (FIRR) was 301%. Other long-term impacts of terracing included farmers' growing of maize on terraced fields as a result of water conservation. Farmers also grew barley on terraced fields for two crop seasons per year unlike the experiences on farms without terraces. Household incomes and food security had improved and soil erosion drastically reduced. Many farmers had adopted terracing doubling the original area under the soil conservation pilot project and consequently improving environmental conservation in the watershed.

According to Posthumus and De Graaff (2005), a cost-benefit analysis of bench terraces was undertaken on the basis of both measured data and that obtained from farmers. In the years 2002 and 2003, five and six sites were selected respectively each with a terraced field ('with' case) and an adjacent sloping field under similar conditions ('without' case). The results indicated that for most farmers, an opportunity cost of labour below the market wage was justified, as they had only temporary off-farm work. Considering these opportunity costs, the labour input in bench terracing was in most cases worthwhile. The same is echoed by Bizoza and Graaff (2012) who reported that a plot level financial cost–benefit analysis was undertaken to examine under which social and economic conditions bench terraces were financially viable in Northern and Southern Rwanda. Farmers' estimates of respective costs and potato yields from plots with subsidized and un-subsidized bench terraces, progressive terraces and plots with no terraces at all were obtained for the analysis. Costs of labour and manure were found to be the most influential for the profitability of bench and progressive terraces. While the cost–benefit analysis, using market prices, showed that bench terraces would be hardly profitable, an analysis with opportunity costs for labour and manure indicated that bench terraces and even more progressive terraces were financially profitable. In this study the cost gross margins for CP4 and those of the other treatments indicated that terracing is profitable. In a review on water-use efficiencies of wheat, maize and sorghum (Beukes *et al*., 2004) reported that a realistic goal for producers in dryland regions is to increase growing-season evapotranspiration of grain crops by 25 mm. The effect of this on grain yield was estimated on the basis of grain-yield and water-supply information. The review on the three crops varied considerably depending on yield levels and climate conditions in the many studies conducted worldwide. They concluded however that as a general guide, 1.7 kg of maize grain, 1.5 kg of sorghum or 1.3 kg of wheat can be produced in dryland regions per additional cubic metre of water used by evapotranspiration. These values can be refined where sufficient local data are available. Using these values, some preliminary benefit/cost estimates can be made regarding the amount of investment that can be made based only on production. However, there may be social and environmental benefits that will justify investment costs far beyond those strictly for increased grain production. Based on the water-use efficiency values above, maize yield could be increased by 0.42 tonnes/ha, and sorghum by 0.38 tonnes/ha. The 1988–1990 average yields of maize and sorghum in semi-arid regions of developing countries were 1.13 and 0.65 tonnes/ha, respectively (FAO, 1996a). Therefore, increasing plant water use by only 25 mm could potentially raise the average yields of maize and sorghum by 38 and 58 percent, respectively. These large gains from such a small amount of additional water use are feasible because the threshold amounts of water required for grain production are already met and any additional water increases grain production directly, when the water is availed at the critical period of the growing season and that sufficient plant nutrients are available to take advantage of the additional water use (Koohafkan and Stewart, 2008). Increased soil-water storage also influences the effects of fertilizer and other inputs. FAO (2000b) developed a generalized relationship between water use and cereal grain yields showing that the impact of inputs increased sharply with yields.

CHAPTER FIVE

5.0 CONLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Terraces overtime have been used for the control of soil loss due to water erosion but they are also known to increase surface moisture storage capacity, encourage infiltration, and conserve more water in the root area for plant growth. This study revealed that terraces influence moisture and nutrient variability in terraced farms by creating zones moisture and nutrient accumulation next to the terrace embankment and zones of moisture and nutrient loss in the upper terrace position. This nutrient and moisture variability was shown to have effect on crop performance and eventual yield. The study showed that soil carbon, phosphorus, potassium and total nitrogen increased down the slope suggesting that slope had an effect on their availability and uptake by plants resulting in higher yields at the lower slope position next to the terrace embankment. It was also observed there was lateral seepage of water from the terrace ditch resulting in better crop performance at the upper middle slope position. On the performance of maize and beans as influenced by the season slope and cropping pattern, the results indicated that there were significant differences ($P \leq 0.05$) in slope position for all crop growth parameters. The lower slope position was found to have significantly higher ($p \leq 0.05$) mean values for all growth and yield parameters. CP4 (control) registered the lowest values in all crop growth parameters, an indication that terracing has effect on crop performance. Cropping pattern three (sole maize) had higher moisture content readings, above ground biomass yields as well as grain yields though not significantly different, from the other treatments except for the control. The yields and gross margins of sole and intercrops did not show significant differences in all seasons.

From the results of this study, it is possible to conclude that terracing reduced soils erosion, improved soil moisture and nutrients resulting in increased crop yield, implying that there is an untapped potential for yield improvement. The investigation concluded that terracing had effect on productivity and the farmers can benefit from the spatial nutrient and water variability as a low technology precision farming for increased crop yields. Terracing improves the basic agricultural cultivation conditions and agricultural development efficiency, establishing a base for sustainable agricultural development in the future, and promoting local society and economic stability in Suswa, Narok County. This can also be replicated in other arid and semi-arid regions of Kenya.

5.2 Recommendations

- Based on the findings of this research crop performance can be improved through appropriate cropping patterns at different slope position in terraced fields.
- The yields and gross margins of sole and intercrops in the lower slope position did not show significant differences in all seasons, intercropping should be encouraged to optimise the use of land, time and labour
- The most appropriate cropping patterns for the study area is CP2, where there the will be a maize and bean intercrop in the upper terrace position and sole beans in the middle terrace position
- Terracing and maintenance of terrace ditch and embankment should be encouraged for the purpose of harvesting rainwater and distribution within the terraced field.
- Future research should be directed towards understanding different soil types so as to come up with suitable cropping patterns as well as their nutrient requirements.
- The study also has great policy implications for the drylands of Kenya on how the soil quality as well as crop yield could be improved and maintained sustainably with proper design and implementation of soil conservation structures.

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APPENDICES

Appendix 1: Impacts of terracing

Benefits	Land users/community level	Watershed/landscape	National /global level
Production	Increase in crop yields Increase in fodder production through grass on risers,	reduced risk and loss of production access to clean drinking water	improved food and water security
Economic	Increased farm income (long term)	-less damage to off-site infrastructure -Stimulation of economic growth	improved livelihood and well- being
Ecological	Reduced soil loss increased soil moisture reduced soil erosion increased infiltration rates decrease in runoff velocity and control of dispersed runoff increase in soil fertility (long term) biodiversity enhancement improved micro-climate	reduced degradation and sedimentation Improved water quality Increased water availability Intact ecosystem	increased resilience to climate change reduced degradation and desertification incidence and intensity enhanced biodiversity
Socio-cultural	Improved conservation / erosion knowledge community institution strengthening	increased awareness for environmental 'health' attractive landscape	protecting national heritage
Constraints		**How to overcome**	
Production	Loss of land for production due to risers of terraces, ditches for Fanya juu / chini, vegetative strips, etc. The constructions can easily be damaged by cattle interference Planting of vegetative strips falls in the period with highest agricultural activity If not adequately managed soil and water conservation function can be lost or can even be accelerated Competition for water and nutrients in the case of vegetative barriers	integrating and incorporating vegetative measures in the system, widen the spacing between bunds, make bund area productive (e.g. grass on terraces for livestock), increase productivity of fodder trees on bunds, etc. Controlled grazing management of the terraces Capacity building and training for appropriate management of the measures	

Economic	High investments costs, usually exceeding short term benefits Shortage of labour, especially for the construction; very high labour input is needed. Some cross-slope barriers can also lead to high maintenance requirement, e.g. soil bunds. Shortage of construction material and hand tools Lack of market infrastructure	Credits and financial incentives for initial investments should be easily accessible to land users Establishment with labour-sharing or merry go round groups Financial incentives or credit facilities availed For maintenance land users should be organised (individually or in groups) to undertake maintenance and repairs
Ecological	Possible water logging before bund / embankment Uneven flood water distribution, breakages of terraces Rodent and other pests hiding in the vegetation Competition of vegetative strips and bunds with crop Unprotected bunds, which have not been planted with grass, are prone to erosion	additional measures such as vegetation / mulch cover Maintenance and adjustments of the barriers Provision of appropriate measures, Provision of rodent and pest controlling mechanisms Trimming of vegetation during crop growing period Additional measures such as vegetation / mulch cover to reduce runoff
Socio-cultural	Often traditional system, but not properly maintained, especially when populations move away from rural areas	Incentives for 'renovation' of traditional structures (e.g. Konso terraces in Ethiopia, where food for work was used)

Source: FAO, 2002

Appendix 2: Analysis of variance for maize Height (cm) at tasseling

```
Source of variation          d.f.  (m.v.)       s.s.       m.s.     v.r.   F pr.
 REP stratum
SEASON.CP                      12             5808.34     484.03
Residual                      -10             3760.52
 REP.*Units* stratum
SEASON                          3           159941.73   53313.91  1896.50  <.001
SLOPE                           4           251983.00   62995.75  2240.91  <.001
CP                              4            17459.66    4364.91   155.27  <.001
SEASON.SLOPE                   12             9596.67     799.72    28.45  <.001
SEASON.CP                      12            11352.17     946.01    33.65  <.001
SLOPE.CP                       16             5659.97     353.75    12.58  <.001
SEASON.SLOPE.CP                45     (3)     4289.85      95.33     3.39  <.001
Residual                      765    (33)    21505.45      28.11
 Total                        863    (36)   483163.03
```

Appendix 3: Analysis of variance for maize LAI at tasseling

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum						
SEASON.CP	12		29.4243	2.4520		
Residual	-10		4.8575			
REP.*Units* stratum						
SEASON	3		202.1769	67.3923	672.85	<.001
SLOPE	4		640.1460	160.0365	1597.81	<.001
CP	4		34.2204	8.5551	85.41	<.001
SEASON.SLOPE	12		65.6885	5.4740	54.65	<.001
SEASON.CP	12		23.0987	1.9249	19.22	<.001
SLOPE.CP	16		23.7248	1.4828	14.80	<.001
SEASON.SLOPE.CP	45	(3)	16.2583	0.3613	3.61	<.001
Residual	765	(33)	76.6224	0.1002		
Total	863	(36)	1102.6858			

Appendix 4 Analysis of variance for number of maize leaves at tasseling

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum						
SEASON.CP	12		62.4228	5.2019		
Residual	-10		4.4899			
REP.*Units* stratum						
SEASON	3		1002.4669	334.1556	604.36	<.001
SLOPE	4		2091.0140	522.7535	945.46	<.001
CP	4		89.8543	22.4636	40.63	<.001
SEASON.SLOPE	12		56.4632	4.7053	8.51	<.001
SEASON.CP	12		78.8537	6.5711	11.88	<.001
SLOPE.CP	16		47.3308	2.9582	5.35	<.001
SEASON.SLOPE.CP	45	(3)	34.9973	0.7777	1.41	0.043
Residual	765	(33)	422.9752	0.5529		
Total	863	(36)	3826.2176			

Appendix 5: Analysis of variance for maize height (cm) at 9leaf

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum						
SEASON.CP	12		42135.44	3511.29		
Residual	-10		10209.58			
REP.*Units* stratum						
SEASON	3		291.31	97.10	1.69	0.167
SLOPE	4		181950.41	45487.60	793.82	<.001
CP	4		5983.16	1495.79	26.10	<.001
SEASON.SLOPE	12		903.99	75.33	1.31	0.205
SEASON.CP	12		8094.11	674.51	11.77	<.001
SLOPE.CP	16		5145.71	321.61	5.61	<.001
SEASON.SLOPE.CP	45	(3)	3680.31	81.78	1.43	0.037
Residual	765	(33)	43836.28	57.30		
Total	863	(36)	293770.53			

Appendix 6: Analysis of variance for maize LAI at the 9th leaf stage

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum						
SEASON.CP	12		9.40310	0.78359		
Residual	-10		0.41550			
REP.*Units* stratum						
SEASON	3		0.62265	0.20755	4.47	0.004
SLOPE	4		170.01806	42.50451	915.13	<.001
CP	4		4.71043	1.17761	25.35	<.001
SEASON.SLOPE	12		1.53810	0.12817	2.76	0.001
SEASON.CP	12		4.06731	0.33894	7.30	<.001
SLOPE.CP	16		2.88767	0.18048	3.89	<.001
SEASON.SLOPE.CP	45	(3)	2.94887	0.06553	1.41	0.042
Residual	765	(33)	35.53135	0.04645		
Total	863	(36)	226.19283			

Appendix 7: Analysis of variance for number of maize leaves at the 9th leaf stage

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum						
SEASON.CP	12		4.7221	0.3935		
Residual	-10		3.2727			
REP.*Units* stratum						
SEASON	3		0.9345	0.3115	1.14	0.334
SLOPE	4		571.4927	142.8732	520.89	<.001
CP	4		10.0445	2.5111	9.16	<.001
SEASON.SLOPE	12		4.3642	0.3637	1.33	0.198
SEASON.CP	12		2.3045	0.1920	0.70	0.752
SLOPE.CP	16		11.4965	0.7185	2.62	<.001
SEASON.SLOPE.CP	45	(3)	11.6653	0.2592	0.95	0.577
Residual	765	(33)	209.8277	0.2743		
Total	863	(36)	813.7396			

Appendix 8: Analysis of variance for maize yield (tha^{-1}) for seasons I, II and III

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		29.6500	14.8250	59.38	
REP.*Units* stratum						
SEASON	1		349.5359	349.5359	1400.14	<.001
SLOPE	4		396.3510	99.0877	396.92	<.001
CP	4		13.8908	3.4727	13.91	<.001
SEASON.SLOPE	4		8.1879	2.0470	8.20	<.001
SEASON.CP	4		3.3865	0.8466	3.39	0.010
SLOPE.CP	15	(1)	7.3937	0.4929	1.97	0.018
SEASON.SLOPE.CP	15	(1)	4.0121	0.2675	1.07	0.384
Residual	236	(12)	58.9160	0.2496		
Total	285	(14)	849.6799			

Appendix 9: Analysis of variance for maize biomass (kgha^{-1}) for seasons II and IV

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		33556413.	16778207.	66.55	
REP.*Units* stratum						
SEASON	1		23149479.	23149479.	91.82	<.001
SLOPE	4		164424833.	41106208.	163.05	<.001
CP	4		22049734.	5512434.	21.87	<.001
SEASON.SLOPE	4		1623086.	405772.	1.61	0.178
SEASON.CP	4		1701253.	425313.	1.69	0.160
SLOPE.CP	16		9497899.	593619.	2.35	0.006
SEASON.SLOPE.CP	15	(1)	1014491.	67633.	0.27	0.997
Residual	93	(5)	23445765.	252105.		
Total	143	(6)	274018782.			

Appendix 10: Analysis of variance for soil moisture (%) at 30cm depth

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	33.781	16.890	12.94	
REP.*Units* stratum					
SEASON	3	363.665	121.222	92.85	<.001
SLOPE	2	354.613	177.306	135.81	<.001
CP	4	16.600	4.150	3.18	0.016
SEASON.SLOPE	6	49.794	8.299	6.36	<.001
SEASON.CP	12	25.483	2.124	1.63	0.093
SLOPE.CP	8	12.908	1.613	1.24	0.284
SEASON.SLOPE.CP	24	13.504	0.563	0.43	0.990
Residual	118	154.051	1.306		
Total	179	1024.398			

Appendix 11: Analysis of variance for soil moisture (%) in maize at the 9th leaf stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	133.2656	66.6328	73.02	
REP.*Units* stratum					
SEASON	3	488.5987	162.8662	178.47	<.001
SLOPE	4	2100.1699	525.0425	575.35	<.001
CP	4	72.4534	18.1133	19.85	<.001
Depth	1	485.8252	485.8252	532.38	<.001
SEASON.SLOPE	12	59.3608	4.9467	5.42	<.001
SEASON.CP	12	61.3730	5.1144	5.60	<.001
SLOPE.CP	16	79.5166	4.9698	5.45	<.001
SEASON.Depth	3	35.6617	11.8872	13.03	<.001
SLOPE.Depth	4	1.7897	0.4474	0.49	0.743
CP.Depth	4	5.5393	1.3848	1.52	0.196
SEASON.SLOPE.CP	48	34.0106	0.7086	0.78	0.859
SEASON.SLOPE.Depth	12	21.2166	1.7680	1.94	0.029
SEASON.CP.Depth	12	15.3826	1.2819	1.40	0.161
SLOPE.CP.Depth	16	6.0553	0.3785	0.41	0.979
SEASON.SLOPE.CP.Depth	48	16.7940	0.3499	0.38	1.000
Residual	398	363.1985	0.9126		
Total	599	3980.2116			

Appendix 12: Analysis of variance for soil moisture (%) in maize at tasseling

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	215.361	107.681	99.51	
REP.*Units* stratum					
SEASON	3	1040.636	346.879	320.56	<.001
SLOPE	4	1757.998	439.500	406.15	<.001
Depth	1	355.663	355.663	328.68	<.001
CP	4	115.644	28.911	26.72	<.001
SEASON.SLOPE	12	31.489	2.624	2.42	0.005
SEASON.Depth	3	33.559	11.186	10.34	<.001
SLOPE.Depth	4	5.147	1.287	1.19	0.315
SEASON.CP	12	47.384	3.949	3.65	<.001
SLOPE.CP	16	104.200	6.513	6.02	<.001
Depth.CP	4	8.891	2.223	2.05	0.086
SEASON.SLOPE.Depth	12	21.998	1.833	1.69	0.066
SEASON.SLOPE.CP	48	30.337	0.632	0.58	0.988
SEASON.Depth.CP	12	37.430	3.119	2.88	<.001
SLOPE.Depth.CP	16	5.211	0.326	0.30	0.996
SEASON.SLOPE.Depth.CP	48	14.164	0.295	0.27	1.000
Residual	398	430.678	1.082		
Total	599	4255.790			

Appendix 13: Analysis of variance for N (%) maize grain nutrient uptake in seasons I ,II & III

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum					
SEASON	2	0.003227	0.001613		
REP.*Units* stratum					
SEASON	2	3.228862	1.614431	525.39	<.001
SLOPE	4	7.632208	1.908052	620.94	<.001
CP	4	2.729499	0.682375	222.07	<.001
SEASON.SLOPE	8	0.531368	0.066421	21.62	<.001
SEASON.CP	8	0.036352	0.004544	1.48	0.170
SLOPE.CP	16	10.546049	0.659128	214.50	<.001
SEASON.SLOPE.CP	32	0.127680	0.003990	1.30	0.152
Residual	148	0.454778	0.003073		
Total	224	25.308456			

Appendix 14: Analysis of variance for P (ppm) nutrient uptake in maize grain in seasons I, II and III

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum					
SEASON	2	489957.	244978.		
REP.*Units* stratum					
SEASON	2	244627.	122313.	4.09	0.019
SLOPE	4	38026725.	9506681.	318.04	<.001
CP	4	5952391.	1488098.	49.78	<.001
SEASON.SLOPE	8	256254.	32032.	1.07	0.386
SEASON.CP	8	367759.	45970.	1.54	0.149
SLOPE.CP	16	20833259.	1302079.	43.56	<.001
SEASON.SLOPE.CP	32	782787.	24462.	0.82	0.742
Residual	148	4423874.	29891.		
Total	224	74703425.			

Appendix 15: Analysis of variance for K (ppm) nutrient uptake in maize grain in seasons I, II and III

Variate: ppmK

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum					
SEASON	2	35657.	17828.		
REP.*Units* stratum					
SEASON	2	66253181.	33126590.	413.93	<.001
SLOPE	4	104633934.	26158484.	326.86	<.001
CP	4	24752588.	6188147.	77.32	<.001
SEASON.SLOPE	8	2564803.	320600.	4.01	<.001
SEASON.CP	8	414423.	51803.	0.65	0.737
SLOPE.CP	16	75722714.	4732670.	59.14	<.001
SEASON.SLOPE.CP	32	2459490.	76859.	0.96	0.534
Residual	148	11844295.	80029.		
Total	224	289763496.			

Appendix 16: Analysis of variance for bean yield (kgha^{-1}) for seasons

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		35917.	17959.	4.74	
REP.*Units* stratum						
SEASON	1		2122831.	2122831.	559.92	<.001
SLOPE	4		9149033.	2287258.	603.29	<.001
CP	3	(1)	364153.	121384.	32.02	<.001
SEASON.SLOPE	4		1391634.	347908.	91.76	<.001
SEASON.CP	3	(1)	206879.	68960.	18.19	<.001
SLOPE.CP	11	(5)	327209.	29746.	7.85	<.001
SEASON.SLOPE.CP	11	(5)	154948.	14086.	3.72	<.001
Residual	74	(24)	280559.	3791.		
Total	113	(36)	11490955.			

Appendix 17: Analysis of variance for number of bean pods for seasons

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		80.6050	40.3025	41.01	
REP.*Units* stratum						
SEASON	1		176.0056	176.0056	179.11	<.001
SLOPE	4		1598.4193	399.6048	406.64	<.001
CP	3	(1)	47.2586	15.7529	16.03	<.001
SEASON.SLOPE	4		12.2344	3.0586	3.11	0.020
SEASON.CP	3	(1)	0.4032	0.1344	0.14	0.938
SLOPE.CP	11	(5)	115.1798	10.4709	10.66	<.001
SEASON.SLOPE.CP	11	(5)	15.0346	1.3668	1.39	0.195
Residual	74	(24)	72.7193	0.9827		
Total	113	(36)	1732.2544			

Appendix 18: Analysis of variance for soil C (%) nutrient distribution at beginning and at end of trials

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.23242	0.11621	1.36	
REP.*Units* stratum					
SEASON	1	15.76699	15.76699	184.88	<.001
SLOPE	2	2.87351	1.43675	16.85	<.001
CP	4	0.19746	0.04937	0.58	0.679
SEASON.SLOPE	2	2.44511	1.22255	14.34	<.001
SEASON.CP	4	0.15540	0.03885	0.46	0.768
SLOPE.CP	8	0.30669	0.03834	0.45	0.886
SEASON.SLOPE.CP	8	0.31742	0.03968	0.47	0.876
Residual	58	4.94638	0.08528		
Total	89	27.24138			

Appendix 19: Analysis of variance for soil N (%) nutrient distribution at beginning and at end of trials

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.025092	0.012546	8.00	
REP.*Units* stratum					
SEASON	1	0.079614	0.079614	50.78	<.001
SLOPE	2	0.261750	0.130875	83.47	<.001
CP	4	0.009896	0.002474	1.58	0.192
SEASON.SLOPE	2	0.152815	0.076407	48.73	<.001
SEASON.CP	4	0.006505	0.001626	1.04	0.396
SLOPE.CP	8	0.005904	0.000738	0.47	0.872
SEASON.SLOPE.CP	8	0.006708	0.000839	0.53	0.825
Residual	58	0.090935	0.001568		
Total	89	0.639220			

Appendix 20: Analysis of variance for soil K ($Cmolkg^{-1}$) nutrient distribution at beginning and at end of trials

Source of variation	d.f.	s.s.	m.s	v.r.	F pr.
REP stratum	2	1.7017	0.8508	8.37	
REP.*Units* stratum					
SEASON	1	15.4339	15.4339	151.91	<.001
SLOPE	2	2.4594	1.2297	12.10	<.001
CP	4	0.6719	0.1680	1.65	0.173
SEASON.SLOPE	2	1.9806	0.9903	9.75	<.001
SEASON.CP	4	1.2895	0.3224	3.17	0.020
SLOPE.CP	8	0.1827	0.0228	0.22	0.985
SEASON.SLOPE.CP	8	0.3795	0.0474	0.47	0.874
Residual	58	5.8926	0.1016		
Total	89	29.9918			

Appendix 21: Analysis of variance for soil P (ppm) nutrient distribution at beginning and at end of trials

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	596.48	298.24	16.81	
REP.*Units* stratum					
SEASON	1	1790.24	1790.24	100.88	<.001
SLOPE	2	1553.21	776.61	43.76	<.001
CP	4	185.35	46.34	2.61	0.045
SEASON.SLOPE	2	211.83	105.92	5.97	0.004
SEASON.CP	4	166.47	41.62	2.35	0.065
SLOPE.CP	8	79.07	9.88	0.56	0.808
SEASON.SLOPE.CP	8	70.42	8.80	0.50	0.854
Residual	58	1029.27	17.75		
Total	89	5682.35			

Appendix 22: Analysis of variance for soil pH (H_2O) distribution at beginning and at end of trials

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.13563	0.06781	2.89	
REP.*Units* stratum					
SEASON	1	0.07685	0.07685	3.28	0.076
SLOPE	2	0.06191	0.03095	1.32	0.275
CP	4	0.10108	0.02527	1.08	0.376
SEASON.SLOPE	2	0.06960	0.03480	1.48	0.235
SEASON.CP	4	0.14015	0.03504	1.49	0.216
SLOPE.CP	8	0.08337	0.01042	0.44	0.889
SEASON.SLOPE.CP	8	0.07848	0.00981	0.42	0.906
Residual	58	1.36104	0.02347		
Total	89	2.10811			

Appendix 23: Analysis of variance for N (%) nutrient uptake in maize aboveground in seasons II & IV

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		4.43049	2.21525	86.22	
REP.*Units* stratum						
SEASON	1		1.36052	1.36052	52.95	<.001
SLOPE	4		24.49539	6.12385	238.35	<.001
CP	4		3.07390	0.76847	29.91	<.001
SEASON.SLOPE	4		0.13970	0.03493	1.36	0.254
SEASON.CP	4		0.12332	0.03083	1.20	0.316
SLOPE.CP	16		1.65701	0.10356	4.03	<.001
SEASON.SLOPE.CP	15	(1)	0.28451	0.01897	0.74	0.740
Residual	93	(5)	2.38941	0.02569		
Total	143	(6)	37.34908			

Appendix 24: Analysis of variance for K (ppm) nutrient uptake in maize aboveground in seasons II & IV

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		1069685.	534843.	5.00	
REP.*Units* stratum						
SEASON	1		5656.	5656.	0.05	0.819
SLOPE	4		51040599.	12760150.	119.23	<.001
CP	4		542545.	135636.	1.27	0.288
SEASON.SLOPE	4		414.	104.	0.00	1.000
SEASON.CP	4		656787.	164197.	1.53	0.199
SLOPE.CP	16		1073760.	67110.	0.63	0.854
SEASON.SLOPE.CP	15	(1)	358899.	23927.	0.22	0.999
Residual	93	(5)	9952669.	107018.		
Total	143	(6)	63120033.			

Appendix 25: Analysis of variance for P (ppm) nutrient uptake in maize aboveground in seasons II & IV

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		7643.	3822.	2.18	
REP.*Units* stratum						
SEASON	1		29195.	29195.	16.67	<.001
SLOPE	4		5925892.	1481473.	846.06	<.001
CP	4		174849.	43712.	24.96	<.001
SEASON.SLOPE	4		1300.	325.	0.19	0.945
SEASON.CP	4		12665.	3166.	1.81	0.134
SLOPE.CP	16		179659.	11229.	6.41	<.001
SEASON.SLOPE.CP	15	(1)	20601.	1373.	0.78	0.692
Residual	93	(5)	162846.	1751.		
Total	143	(6)	5894463.			